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CURIOSITY
HAS TAKEN
US

Building Better Climate Models

No Tolerance for Sexual Harassment

Cheers, Yawns for Planet Nine

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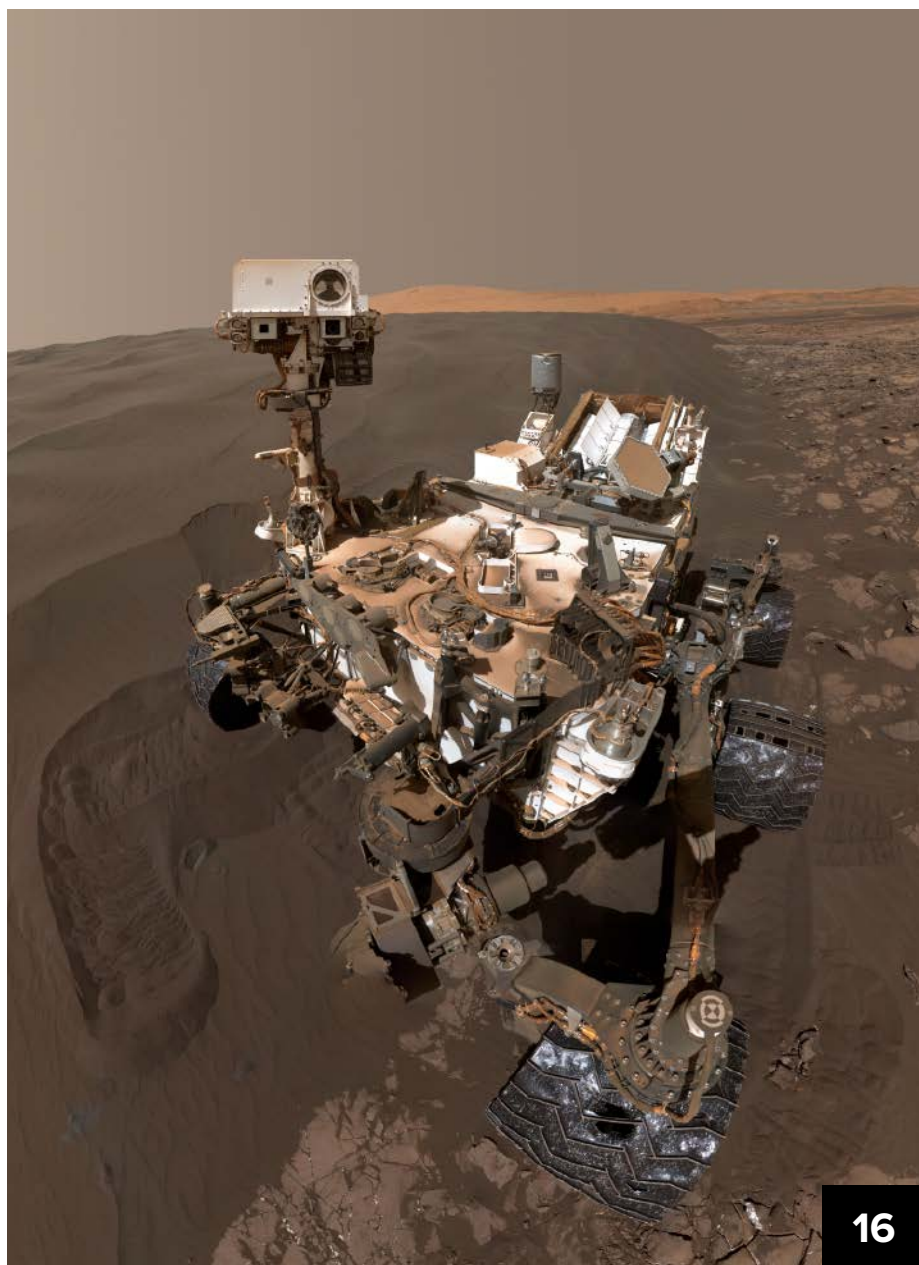
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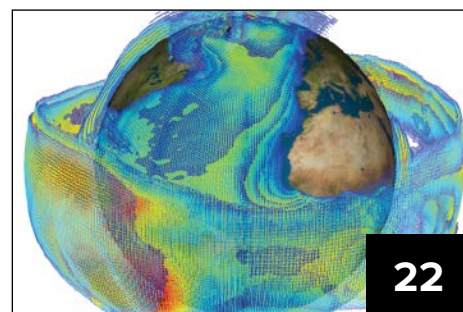
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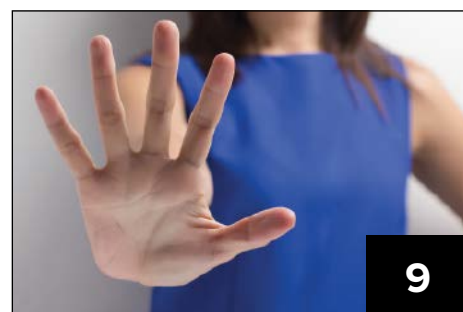


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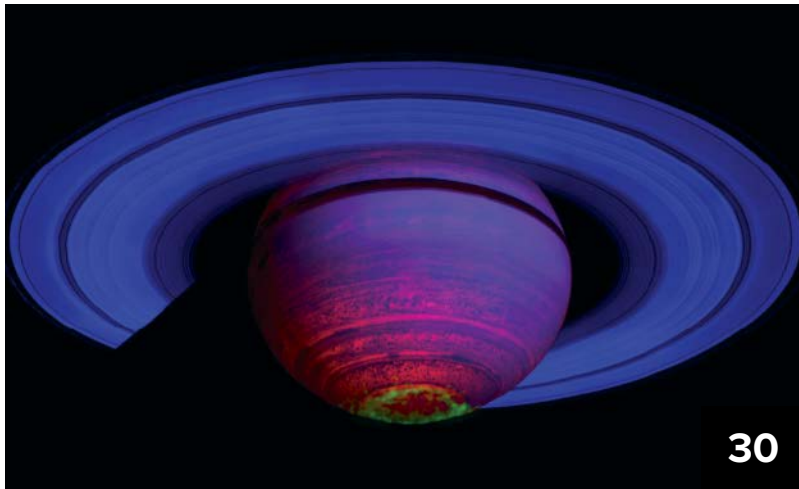
AGU can lead the way in building an environment where sexual and other types of harassment have no place.

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Curiosity rover's first sampling hole, 1.6 centimeters across and 6.7 centimeters deep, drilled on Mars's Mount Sharp. Credit: NASA/JPL-Caltech/MSSSS.

EOS®

Editor in Chief

Barbara T. Richman: AGU, Washington, D. C., USA; eos_brichman@agu.org

Editors

Christina M. S. Cohen
California Institute
of Technology, Pasadena,
Calif., USA;
cohen@srl.caltech.edu

Wendy S. Gordon
Ecologia Consulting,
Austin, Texas, USA;
wendy@ecologiaconsulting
.com

Carol A. Stein
Department of Earth and
Environmental Sciences,
University of Illinois at
Chicago, Chicago, Ill.,
USA; cstein@uic.edu

José D. Fuentes

Department of Meteorology,
Pennsylvania State
University, University
Park, Pa., USA;
juf15@meteo.psu.edu

David Halpern

Jet Propulsion Laboratory,
Pasadena, Calif., USA;
davidhalpern29@gmail
.com

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Marketing: Angelo Bouselli, Marketing Program Manager; Jamie R. Liu, Manager, Marketing

Advertising: Christy Hanson, Manager; Tel: +1-202-777-7536; Email: advertising@agu.org

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Christine W. McEntee, Executive Director/CEO

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American Geophysical Union

Oil, Coal Industry Leaders Fault Obama Policies at Energy Forum



Sergey Novikov/Adobe Stock

Oil refineries in Salt Lake City.

The heads of two U.S. fossil fuel industry associations took the Obama administration to task at an energy forum for what they said is a misguided and unfair energy policy. At the same meeting, a solar energy association leader applauded federal policies as favorable for growth in his industry.

The administration's approach to energy regulation and support harms the fossil fuel industry, picks energy favorites, and forces higher energy costs on consumers, said top executives of the American Petroleum Institute (API) and the National Mining Association (NMA) at a recent State of the Energy Industry Forum organized by the United States Energy Association in Washington, D. C. Meanwhile, the head of the Solar Energy Industries Association painted a bright picture for solar power in the United States.

API president and CEO Jack Gerard said the oil and natural gas industry and its long-term prospects remain healthy, despite the current downturn in prices. The U.S. model of a market-driven, consumer-focused approach

to energy policy works, he said. "We can grow our economy, provide consumers with abundant lower cost energy, improve our environment, and lead the world in energy production, all, by the way, while fighting the headwinds of almost 100 federal regulations that thwart American energy production," Gerard stated.

Among those regulations, he targeted the administration's Clean Power Plan (<http://bit.ly/CleanP-Plan>), which the U.S. Environmental Protection Agency (EPA) has called "a common sense plan to cut carbon pollution from power plants." Gerard argued that the plan "tilts the scale" of energy markets "as a means to further a particular political ideology" and that the plan overlooks the successes of domestic natural gas producers at lowering electricity prices and reducing carbon emissions.

In an interview with *Eos*, Gerard said that leaving fossil fuels in the ground to reduce greenhouse gases is an "irresponsible" approach. "If you look at the administration's projections, they will tell you by 2040 still 80%

of all the energy we use in the United States will be fossil fuels. So why would we promote a policy that says 'let's go raise costs [for] consumers by keeping the energy in the ground'?"

Pressures on Coal, Including "External Threats"

Speaking for the mining industry at the 21 January forum, NMA president and CEO Hal Quinn said that the global picture for coal remains "bright and very stable." Between 2010 and 2015, 465 gigawatts of power produced by coal came online globally, he said. Quinn added that another 353 gigawatts of coal generation now under construction, mainly in China and India, exceeds by about 7 times the coal capacity that EPA hopes to take offline in the United States by means of the Clean Power Plan.

However, currency fluctuations, the economic slowdown in China, and excess global capacity have hurt U.S. coal exports, Quinn said. Policy-driven "external threats," such as EPA's Mercury and Air Toxics Standards for power plants, "have destroyed 20% of coal markets over a very short period of time," he added (see <http://bit.ly/Merc-Tox-Standards>). Quinn said that he sees the Clean Power Plan as "the biggest threat to the industry's ability to rebound." He said the president should "reembrace" his administration's 2008 commitment to advancing technological solutions, including funding for clean coal technology, which Quinn said could help to significantly reduce emissions.

"We're really going to need technological solutions, not fuel substitution," he said, adding that what the administration wants are "symbolic but very costly gestures to demonstrate what they believe on the world stage would be climate leadership."

A Bright Future for Solar Energy

Rhone Resch, president and CEO of the Solar Energy Industries Association, also addressed the forum. He said solar is strong and getting stronger in the United States and applauded federal support for the industry. He credited the growth in solar to lower prices and a solar investment tax credit, which Congress extended for 5 years in an omnibus appropriations bill that passed last December.

Solar power has reached 1% of total energy generation in the United States, up from 0.1% just 5 years ago, and is expected to hit 3.5% by 2020, Resch said.

"Solar is here," he said. "It's going to be part of the energy mix."

By **Randy Showstack**, Staff Writer

Subtle Seismic Movements May Help Forecast Large Earthquakes

Scientists studying the massive subduction zone off the east coast of Japan have found a correlation between earthquakes and periodic events called “slow slip” wherein the plate moves but the motion produces no discernable seismic signature. The new insight, published recently in *Science* (see <http://bit.ly/Science-paper>), may help scientists better forecast the likelihood of large earthquakes.

When slow-slip events occur, “the possibility of earthquakes [is] higher than normal” because of the stress from the slow-slip events, said Naoki Uchida, lead author on the paper and a seismologist at Tohoku University in Sendai, Japan.

Slowly Slipping Plates

Slow-slip or “aseismic” events can occur at any plate boundary but are observed most clearly in subduction zones. In this study, Uchida and his colleagues investigated those events where the Pacific Plate, an oceanic slab of the Earth’s crust, creeps underneath the continental Okhotsk Plate. Such aseismic motions occur over weeks or months, unlike earthquakes, which happen in seconds.

Slow slip does not produce seismic waves, so seismometers cannot observe it. Rather, scientists track the small, slow movements by recording the motion of GPS receivers buried in the ground. In the Cascadia Subduction Zone off the U.S. Pacific Northwest, for instance, seismologists detect slow-slip events about once every 15 months. These events happen so slowly that the energy equivalent of a magnitude 6.5 event can occur over the course of a month—without anyone even feeling it.

Seismologists have observed slow-slip events in the days following large earthquakes. They have long suspected a connection between those events and earthquakes, but if and how the two are related has remained a mystery.

Japan’s Slow Slip

This new study, published online on 28 January, delves deeper into the relationship

between slow-slip events and larger, felt earthquakes along a subduction zone running parallel to the northeastern coast of Japan. The Japan Trench is notorious for producing large, devastating earthquakes, such as the 2011 Tohoku earthquake and the tsunami it unleashed, which caused more than 15,000 deaths, 300 billion dollars in damage, and a nuclear reactor meltdown.

The researchers looked at 28 years’ worth of data to find small “repeater” earthquakes along the subduction zone, said Roland Bürgmann, a coauthor on the recent paper and a

slow-slip events that occurred during the last few decades,” Bürgmann said.

Better Earthquake Forecasts?

The researchers evaluated more than 6000 repeaters and the slow slip that caused them and found a relatively stable periodicity of slow-slip events—they occur every 1–6 years in some places and every 2–3 years in other places along the subduction zone. The researchers then looked at the occurrence of large earthquakes—magnitude 5 and above—in relation to slow slip and found that when the rate of slow-slip events increased, earthquakes were much more likely to occur. They even found a swarm of slow-slip events along the fault preceding the Tohoku earthquake. The correlation between higher rates of slow-slip events and large earthquakes will hopefully allow for “the development of more

precise and shorter-term earthquake forecasts,” Bürgmann said.

Predicting specific earthquakes remains impossible, according to the U.S. Geological Survey (USGS). However, these new findings and possible future strides in quantifying the relationship between slow slip and earthquakes could lead to better forecasting, said Nadeau. Still, he added, it is highly unlikely that scientists will find a way to predict an earthquake on the basis of slow-slip events alone.

In addition, the slow-slip events were inferred from repeaters, rather than from remote GPS measurements, said Evelyn Roeloffs, a research geophysicist at USGS in Vancouver, Wash., who did not take part in

the new study. “Slow-slip events in subduction zones depart from periodicity in other subduction zones—this location may be unique. The periodicity is not perfect, and it is difficult to quickly assimilate the details in the paper fully enough to decide how strong the observation is.”

John Vidale, director of the Pacific Northwest Seismic Network and professor at the University of Washington, Seattle, who was not involved in the study, lauded the new work as a starting point for more research. “The degree of extra accuracy possible in hazard estimation is not yet clear, but, thanks to Uchida et al., additional work in this direction is now an urgent need.”



AP Photo/Yonhji Shimbun

In 2011, the magnitude 9 Tohoku earthquake and tsunami devastated parts of Japan. Scientists have found that earthquakes are more likely to occur after small, aseismic movements within the subduction zone.

seismologist at the Berkeley Seismological Laboratory at the University of California. These small earthquakes occur frequently, acting as a beacon of sorts that leads scientists to slow-slip events.

Stress caused by the slowly slipping Pacific Plate moving beneath the Okhotsk Plate breaks “small stuck patches,” and seismologists detect the breakage as repeater quakes, Bürgmann said. The authors inferred that where the repeaters occur along the plate matches with the location of slow-slip events. In turn, the frequency of repeaters allows researchers to determine how often the plate slipped aseismically, said Robert Nadeau, another coauthor and seismologist at the Berkeley Seismological Laboratory.

“With thousands of such events in northeast Japan, we can resolve small and large

By JoAnna Wendel, Staff Writer

Proposed Planet Nine Elicits Cheers, Yawns, Hunt for Proof

For more than a century, astronomers have speculated—in vain—that a giant, unseen planet, or even a lurking sister star to the Sun, roams the fringes of the solar system.

Astronomer Percival Lowell, back in 1906, invoked a “Planet X” to explain the then unaccounted for motions of Uranus and Neptune. In 1984, researchers postulated that a dwarf star, dubbed Nemesis, periodically dipped into a relatively dense region of comets in the far reaches of the solar system, sending comets hurtling toward the inner solar system and causing an apparent 26-million-year cycle of mass extinctions on Earth. Those are just a couple of the ghost bodies that never did turn up.

Enter “Planet Nine.” In the *Astronomical Journal* (see <http://bit.ly/P9paper>), researchers recently reported new evidence of another such orb. Although the observations cited by study coauthors Konstantin Batygin and Mike Brown of the California Institute of Technology in Pasadena are indirect and based on a new analysis of previously known data (see <http://bit.ly/Sedna-like>), the report made a sensation, lighting up the journal’s website with nearly a quarter million downloads in the first 5 days after the paper was posted on 20 January.

“Planet X is proposed every time someone sees some sort of anomaly in the outer solar system,” said Brown, an astronomer widely known for his role in helping to demote Pluto to a dwarf planet a decade ago. “Usually those [anomalies] end up being bad data. We think that this is the first time the data actually support the hypothesis,” he told *Eos*.

Kuiper Belt Objects Aligned

The data show an unexplained orbital alignment and common motion of six disparate objects in the Kuiper Belt, the doughnut-shaped reservoir of icy bodies, including Pluto, that lies beyond the orbit of Neptune. Those data have convinced some planetary scientists—but by no means all—that gravitational shepherding of the Kuiper Belt objects by a massive, distant planet best explains the mysteriously matching features.

In a blog entry posted the week after the paper was published (see <http://bit.ly/Search-4-P9>), Brown wrote, “From some very simple calculations, we can show that the probability of these alignments happening due to chance is only about 0.007%. You could also

say that there is a 99.993% chance that the alignments we are seeing in the outer solar system are real, and that we are not simply being fooled into seeing a pattern where none exists.”

“This is the strongest evidence presented so far” for Planet X, said David Nesvorny of the Southwest Research Institute in Boulder, Colo., who analyzes the dynamics of solar system objects but wasn’t involved in the new study.

In 2011, Nesvorny suggested that the present-day architecture of the solar system was best explained if the Sun originally had a fifth giant planet, in addition to Jupiter, Saturn, Uranus, and Neptune. The additional planet would ultimately have been gravitationally kicked out of the solar system—unless a close encounter with a nearby star at just the right time stabilized the orbit, keeping Planet Nine at the solar system’s edge, Nesvorny told *Eos*.



The recently proposed “Planet Nine” orbits far from our Sun, which shines dimly in the background of this artist’s representation of the purported planet. The astronomers who hypothesized Planet Nine suspect that it would be a gaseous planet similar to Uranus and Neptune. Crackles of lightning illuminate patches of the would-be planet’s night side.

Seeing Is Believing

Batygin and Brown’s hypothetical planet would lie 7 times farther away than Neptune does, or at 200 astronomical units (AU), when closest to the Sun, on an elliptical orbit that might take it as far out as 1200 AU, the team reported. One astronomical unit is

the average distance between the Earth and the Sun.

NASA’s Wide-Field Infrared Survey Explorer (WISE) spacecraft, which observes at infrared wavelengths, has ruled out a distant solar system planet the size of Saturn out to 10,000 AU and an object the size of Jupiter out to 26,000 AU (see <http://bit.ly/No-Planet-X>). But the much smaller Planet Nine would glow, dimly, in visible light, not infrared, Brown explained. Batygin and Brown have begun hunting for the object with the National Astronomical Observatory of Japan’s Subaru Telescope on Hawaii’s Mauna Kea.

Some researchers have reacted coolly to the Planet Nine hypothesis. “The paper presents some interesting arguments, [but] I think the claims are being made more strongly than the evidence merits,” said astronomer Brett Gladman of the University of British Columbia in Vancouver, Canada, who was also not part of the study.

“The arguments that Konstantin and Mike have presented are clever and carefully worked out, but it’s not a slam dunk,” said exoplanet hunter David Latham of the Harvard-Smithsonian Center for Astrophysics (CFA) in Cambridge, Mass., likewise unassociated with the new Batygin-Brown work. “It’s still early in the community reaction to the announcement, and other clever people may come up with counterarguments.”

Alignment sans Planet

Astronomers Ann-Marie Madigan of the University of California, Berkeley, and Michael McCourt of the CFA have already presented a different argument. In an article published in the *Monthly Notices Letters of the Royal Astronomical Society* (<http://bit.ly/RAS-paper>) on the same day that Batygin and Brown published their finding, Madigan and McCourt suggest that gravitational interactions among the myriad small icy objects in the outer solar system can suffice on their own to cause the orbital alignment of the six telltale objects in the Kuiper Belt that inspired the Planet Nine hypothesis.

The researchers’ simulations show that gravitational tugs among objects located from about 100 to 10,000 AU from the Sun would drive some of them to form a cone-shaped distribution, inclined to the Kuiper Belt, which in turn could cause the alignments Batygin and Brown studied. “This spontaneous behavior is just something that the disk does on its own—we don’t need to invoke an external reason [such as a ninth planet] for it,” said Madigan, who described her simulations during a 26 January lecture

at the SETI Institute in Mountain View, Calif (see <http://bit.ly/SETI-talk>).

Madigan noted that observations can test the validity of her team's hypothesis. In the past, she said, sky surveys generally weren't looking for faint, distant solar system objects in orbits tilted out of the main Kuiper Belt disk because researchers didn't think many such bodies existed. But two ongoing ground-based sky surveys, the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) and the Dark Energy Camera Legacy Survey (DECam Legacy Survey), can hunt for the cone-shaped distribution of objects that would tilt out of the plane in which the planets orbit the Sun. One object, dubbed 2013 RF98, which has the right coordinates to potentially be part of that distribution, has already been detected by DECam, she said.

Testable Predictions and Other Scenarios

"The good news is that both theories make testable predictions, and we will find out the right answer soon," Madigan said.

In addition to aligning the modestly tilted orbits of some Kuiper Belt objects, Planet Nine should have more radically reoriented the orbits of other Kuiper Belt objects, simulations by Batygin and Brown predict. The unseen planet's gravity would have driven those additional objects into orbits completely perpendicular to the plane in which the solar system's eight known planets orbit the Sun. Over the past 3 years, four such objects have been found. Finding more Kuiper Belt objects with this perpendicular orientation would strengthen the case for Planet Nine, Brown told *Eos*.

Planet Nine and the competing conical distribution of outer solar system objects don't offer the only ways of explaining the alignments of the six Kuiper Belt objects that caught the attention of Batygin and Brown, according to Latham. For instance, a gravitational encounter with a star that passed near the solar system sometime in the past few hundred million years might also do the job, he said.

"How long would the pattern last without a Planet Nine to herd the objects?" Latham mused. "These are not necessarily new ideas, but now there is renewed motivation to look at them. It will be interesting to see if there is a flurry of papers exploring related ideas."

By **Ron Cowen**, Freelance Science Journalist;
email: roncowen@msn.com

Report Stresses Need for Real Research in Undergraduate Classes

No one likes an 8 a.m. chemistry lab featuring the same old experiments every year. Now a high-level committee of scientists and educators is offering insights into the challenges, rewards, and prospects of replacing "cookbook" lab work in undergraduate education with course-based research.

In 2012, the President's Council of Advisors on Science and Technology declared that discovery-oriented research courses should replace standard undergraduate lab work (see http://bit.ly/PCAST_STEM). Then a convocation took place in May 2015 under the auspices of the National Academies of Science, Engineering, and Medicine for a fact-finding mission. The group met to learn how educators are incorporating research into their undergraduate courses and whether those models can be applied across 2-year and 4-year institutions, at freshman to senior levels.

"Bringing research experiences into the academic year course structure will provide opportunities to reach many more students," the committee stated in its report from the convocation, titled *Integrating Discovery-Based Research into the Undergraduate Curriculum* (see <http://bit.ly/convoc-report>).

Hands-on Science

Niccole Cerveny, a geography professor at Mesa Community College in Mesa, Ariz., developed one of the models of undergraduate research highlighted in the December 2015 report. She believes that undergraduate research should be heavily emphasized in course work.

Several years ago, Cerveny's students spent time at the Deer Valley Petroglyph Preserve in Glendale, Ariz., where they studied natural weathering on Native American rock art. The students created a "weathering index" to help park managers strategize on preservation efforts. Because the research was tied so closely with the local community and culture, the students were much more enthusiastic about the hard work that comes along with scientific discovery.

"Even if it wasn't their own culture, there was meaning in engaging in the science," Cerveny said. "They got positive results of being involved in science."

As an undergrad, Cerveny herself experienced a research-based course and values it to this day. "With my own experience in undergrad research, I just really feel strongly that it's the best way to reach students," she said.

Challenges and Looking Ahead

The biggest challenge to integrating course-based research into undergraduate classes is "not adopting but adapting models" that already exist, such as Cerveny's in Arizona,

said Laura Guertin, an Earth science professor at Penn State Brandywine in Media, Pa., who was on the committee that wrote the report. Not every institution or instructor has the same financial or administrative opportunities, so strategies for integrating course-based undergraduate research must

Strategies for integrating course-based undergraduate research must be flexible.

be flexible.

Instructors must also adapt, Guertin said. With set lab exercises, instructors know step by step how an experiment will go and how the students will get there. But if you present students with an unknown research question, "that means you as an instructor have to give up some control," Guertin said.

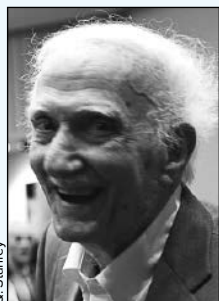
Guertin also pointed out other challenges, such as procuring financial aid for students; providing instructors with sufficient administrative support; and providing support to non-traditional students, such as single parents, those with disabilities, or those in the military.

After meeting to develop a strategy to incorporate more undergraduate course-based research, the committee intends to release a new report in the coming year.

By **JoAnna Wendel**, Staff Writer

Editor's Note: For a personal account about the 3-day convocation that resulted in the report, visit <http://bit.ly/Convoc-On-GeoEdTrek> to read Guertin's three-part blog post on the AGU Blogosphere.

James Wynne Dungey (1923–2015)



Jim Dungey at 90, January 2013.

James “Jim” Dungey, a pioneering solar terrestrial scientist, died 9 May 2015 at the age of 92. He is best known for seminal and, at times, legendary work on magnetospheric phenomena and geospace. He laid the foundation for our current understanding of solar-terrestrial coupling.

Early Research

Jim was born and grew up in Stamford, Lincolnshire, where his father was a schoolteacher. He got his bachelor’s degree from Cambridge in 1947. During World War II, he worked at British Thompson Houston in Rugby, U.K., on developments for radar.

Upon graduating, Jim stayed at Cambridge to pursue a Ph.D. with Fred Hoyle, who, at the time, was writing a monograph on solar physics. Hoyle had been struck by a concept proposed by Ron Giovanelli of the University of Sydney that magnetic neutral sheets on the Sun could give rise to solar flares.

Jim was asked to look at a different context for the Giovanelli problem and investigate whether the formation of a neutral sheet in the magnetic cavity on the night-side of Earth could produce an aurora. He would work on and off on this problem for much of the rest of his career.

Hoyle and Dungey assumed from the start that there was a substantial solar field present near Earth, itself a revolutionary position to take in Britain in the 1940s. Only Hannes Alfvén had previously made such a suggestion [Alfvén, 1939]. Where the terrestrial field and solar field were opposed, neutral sheets would form on both the sunward and antisunward sides of Earth. Jim concluded that a neutral sheet in such conditions could accelerate plasma in a process now called reconnection (see <http://bit.ly/Mag-Reconnect>).

Where the magnetic field lines from the neutral sheet region met the upper atmosphere of Earth, electrons accelerated by reconnection and guided by the field would generate the aurora, in Jim’s picture. Topologically, it was straightforward to see that the feet of the field lines on which the aurora could be excited would form a ring, the auroral zone, around each pole just as had been long known to exist. He went on to propose that poleward of the zone, “open” field lines would connect Sun and Earth. Equatorward of the zone, “closed” field lines would have both ends connected to Earth.

Today, few people would question Jim’s description. Nonetheless, in the 1950s, his thesis work on magnetic reconnection proved hard to publish. The journal of record for a British researcher at the time was *Monthly Notices of the Royal Astronomical Society* (MNRAS). He lost a battle with two much more senior referees, and the paper was rejected. On the advice of Sydney Chapman, he submitted the work to *Philosophical Magazine*, where it was finally accepted [Dungey, 1953].

In 1950, Jim became a postdoctoral fellow in Sydney working with Giovanelli. He loved Australia, and although he completed his Ph.D. defense remotely from there and the subsequent battle with MNRAS occupied him, he did some interesting new work.

For example, with R. E. Loughhead, he wrote a paper on twisted magnetic fields in astrophysical plasmas [Dungey and Loughhead, 1954], effectively deriving the Kruskal-Shafranov criterion (see <http://bit.ly/K-S-criterion>) for what is now known as the kink instability for fusion plasmas some years before the secret work of Vitaly Shafranov in the Soviet Union and Martin Kruskal in the United States was finally published in the open literature.

Jim always delighted in recalling his astonishment at receiving preprint requests from obscure addresses around the world.

Revelations About the Magnetosphere

Jim then moved to Pennsylvania State University’s (Penn State) Ionosphere Research Laboratory in 1953. In 1954, while at Penn State, Jim wrote one of the great papers of his career, an unpublished report with the shorthand title of “Electrodynamics of the Outer Atmosphere.” In the paper, he discussed a number of basic magnetospheric phenomena—the ideas that standing Alfvén waves would form along field lines and that the outer magnetospheric boundary would be subject to Kelvin-Helmholtz instability—as well as how magnetohydrodynamic waves would interact with the ionosphere, 5 years before the magnetosphere was even formally identified!

The paper was circulated hand to hand among elite researchers during the 1960s and 1970s. Why this paper was not published at the time is not clear. It did form a National Science Foundation contract report and was for some years available from Penn State. Over the next decade, as the International Geophysical Year took place

Where the magnetic field lines from the neutral sheet region met the upper atmosphere of Earth, electrons accelerated by reconnection and guided by the field would generate the aurora, in Dungey’s view.

and the space age began, more and more became clear about the existence of the magnetosphere, and Jim published, in separate places, much of the 1954 report (see <http://bit.ly/NSF-report>).

Although Jim retained a visiting position at Penn State well into the 1960s, he returned to Cambridge as an ICI Fellow in 1957. There he wrote a wonderfully dense monograph, *Cosmic Electrodynamics*, for Cambridge University Press [Dungey, 1958], which he once described to me as an exercise in “writing down everything I knew.” It

is long out of print but well worth reading still.

In January 1961, *Physical Review Letters* published his now seminal paper on the reconnection model of the magnetosphere [Dungey, 1961]. Although the basic ideas of the paper drew from Jim's Ph.D. thesis and he refined his theories while at Penn State, it wasn't until he was sitting in a café in Paris watching the motion his coffee made as he stirred it that he had the final insight needed to complete his research. The pattern milk made as it was stirred into the coffee reminded him of the storm time ionospheric electrical current system. It was a eureka

moment. Suddenly, he realized that Earth's polar magnetic field must be stirring the ionosphere, and it must be because the field connected directly to the solar field, as his thesis work had described. Jim's open (or reconnection) magnetospheric model became the foundation of modern understanding of solar terrestrial coupling.

Jim's conclusion, however, was slow to gain wide acceptance. This was despite the fact that by 1966 Don Fairfield, one of Jim's Penn State students, had produced evidence that a southward interplanetary field (favoring magnetic reconnection between terrestrial and solar fields) controlled ionospheric magnetic disturbances [Fairfield and Cahill, 1966]. In 1970, Aubry *et al.* [1970] showed the magnetopause erosion uniquely predicted by Jim's model. Even so, it was only with the direct measurement of plasma acceleration consistent with magnetic reconnection at the magnetopause [Paschmann *et al.*, 1979] that doubts dissolved.

Probing Geospace

Following Cambridge, Jim took a faculty position at Kings College in Newcastle (now Newcastle University), and then, because of his increasing reputation for knowledge of Earth's radiation environment, he was appointed to the U.K. Atomic Weapons Research Establishment in Aldermaston. In 1965, he settled at Imperial College in London, where he remained for nearly 20 years until his retirement in 1984.

The 1961 paper's massive influence can often distract attention from the results of the other seeds he sowed. He was a theorist, but following the data explosion of the 1957–1958 International Geophysical Year and as the space age developed and in situ measurements from space were obtained, Jim reveled in developing theory in the late 1950s and the 1960s inspired by the emerging new information on what is now called geospace. His fascination with the collision-free plasmas of geospace lay in nature's departures from expectations derived from classical electromagnetism or the theory of gases. Stimulated very low frequency emission intrigued him immensely, as did auroral currents and acceleration—and, always, collision-free reconnection.

With his U.S. colleagues, he used the Liouville theorem to show that the radiation belts had an external origin (see <http://bit.ly/studies-of-protons>). He developed theories of radiation belt stability using whistler mode waves that were the precursor of the now standard Kennel–Petschek model, but he pushed the ideas into a different frequency domain to suggest that bounce-drift resonance with magneto-hydrodynamic waves could mediate radial diffusion of the ring current (see <http://bit.ly/ring-current>).

In 1966, he proposed a four-spacecraft Tetrahedral Observatory Probe System to the European Space Research Organisation (the predecessor of the European Space Agency (ESA)). His idea finally came to fruition in 2000, when ESA launched the four Cluster spacecraft. Determination of the detailed structure of large-scale currents, Kelvin–Helmholtz boundary waves, the auroral acceleration region, the dayside and nightside reconnection regions, and the bow shock became possible, just as he had envisaged.

An Eccentric Visionary

Few people's reputations grow as much as Jim's did after retirement. He was honored postretirement with the Fleming Medal from AGU; honorary membership from the European Geophysical Society, its highest honor; and a Gold Medal from the Royal Astronomical Society (RAS) of London,

which recently established an annual James Dungey Lecture.

A special RAS meeting celebrated his 90th birthday in 2013 (see <http://bit.ly/RAS-mtg>). The picture on the previous page shows him exuberant and happy on that day. A Festschrift [Southwood *et al.*, 2015] was recently published.

Jim was a widely respected man but definitely an eccentric. He left his mark on all those who worked closely with him, but they had to learn his way of thinking, and it could be hard. His communication could be telegraphic in the extreme, as is evidenced by the shortness of his papers and his 1958 book. Moreover, when working with him, his quick physical intuition could leave one floundering behind. It is sometimes said he did not suffer fools, and certainly, he could unintentionally offend those who could not follow his arguments. Nonetheless, he was a kind man, and I think that it is truer to say that he tended to say it as he saw it.

Recent detective work by Peter Cargill in the archives of RAS has revealed the names of the two referees who long ago rejected Jim's Ph.D. thesis for publication in MNRAS. I find it ironic that one of them was my undergraduate tutor, who, a decade later, recommended me to Jim as a Ph.D. student. I have always been grateful for that unlikely recommendation.

Although it was hard work to keep up with him, Jim had an endless capacity to surprise. He was a great mentor and became a good friend.

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By **David Southwood**, Imperial College, London; email: d.southwood@imperial.ac.uk

Steps to Building a No-Tolerance Culture for Sexual Harassment



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In the past 2 weeks, two new egregious cases of professors sexually harassing students—and getting away with it for years—have hit the news, following a high-profile case that became public in October 2015. In that first case, a professor sexually harassed students for decades at two institutions, whose administrators turned a blind eye to student complaints. In another, recently brought to light on the floor of the U.S. House of Representatives, a professor sexually denigrated his students. In the third, a young professor fired a graduate student after she did not reciprocate his sexual advances. These cases have raised broad public awareness about a permissive culture of harassment and bullying (see <http://bit.ly/AstroSH1>, <http://bit.ly/AstroSH2>, and <http://bit.ly/AstroSH3>).

We all know similar horrible stories, be it from personal experience or from our friends and colleagues. Sexual harassment is a problem in science, yet it is not just a science problem. It happens in every discipline, on the street, in industry, and in government.

As educators and science professionals, we have a social contract with our students, trainees, and staff to provide safe spaces for learning and employment where people are treated with dignity. We also have a social contract with society to pursue science for the benefit of humankind. If we break our social contract in the first, we can hardly expect to earn the trust of the public in the second.

Harassment endangers the personal, professional, physical, and emotional well-being of individuals and their communities. It can exploit differences in religion, race, class, ability, sexual orientation, and gender identity and is especially toxic when perpetrated by people in positions of power. All these forms of discrimination have no place in our community.

We believe that as the largest scientific society representing the Earth and space sciences, with 60,000 members, AGU has a responsibility to take a leadership role in creating a no-tolerance culture for harassment in our community.

The Scope of Sexual Harassment

Harassment can have especially injurious effects in disciplines with low diversity, such as the geosciences. Anyone can experience sexual harassment, although women and transgendered people are the most common targets.

Women made up 39% of U.S. bachelor's degrees in the Earth, atmospheric, and ocean sciences in 2011 [*National Center for Science and Engineering Statistics*, 2015] but only 20% of faculty in these fields [Glass, 2015]. Of these, Black, Hispanic, American Indian, Alaska Native, and Asian Pacific Islander women represented only 5% and 7% of bachelor's degrees and tenure-track faculty, respectively (as reported by *National Center for Science and Engineering Statistics* [2015]). These low numbers can lead to feelings of isolation,

professional insecurity, and increased vulnerability [Holmes et al., 2015].

In a 2010 member survey by the Earth Science Women's Network (ESWN), 51% of almost 500 female respondents indicated that they had experienced sexual harassment sometime during their career [Archie and Laursen, 2013]. The survey did not explore what proportion pursued formal complaints, but other data suggest that very few incidents generally are reported (see <http://bit.ly/ReportSH>). This can be due to targets not knowing where to turn for help [Clancy et al., 2014], active discouragement by superiors, and fear of repercussions.

Another reason given for why many incidents go unreported is a lack of confidence that reporting will lead to a satisfactory outcome and remove the problem. The failure of academic institutions to protect their students and employees is highlighted by an open U.S. federal investigation into the mishandling of more than 250 sexual assault cases in 161 universities (see <http://bit.ly/Title9SA>).

Outside the university boundaries, students are vulnerable in disciplines with research-related travel away from home. In a 2014 survey of field archaeologists [Clancy et al., 2014], 71% of women respondents and 41% of men reported receiving inappropriate comments, and 26% of women and 6% of men reported experiencing sexual assault while conducting field research. Female trainees disproportionately reported unwanted sexual attention coming from their superiors. Similar data for the geosciences do not exist and need to be addressed, as the enrollment of students in geoscience field camps continues to increase, reaching almost 3000 in 2013 [American Geosciences Institute, 2013].

Academic Institutions Often Protect the Harasser

The three recent sexual harassment cases to hit the news further show a lack of commitment from institutions to take the problem of harassment seriously. When the violators are professors, they suffer few, if any, disciplinary actions with real professional consequences, especially when they are renowned in their field and well funded. If there is an outcome to a report of harassment, victims may see their violators "punished" with sabbatical-like leaves (with relief from teaching and service but no curtailment of their research), career advancement at another university, or early retirement with full benefits.

This normalization of unethical—and illegal—behavior is driven by the prioritization of research funding and prestige. The practice is dangerous: Harassment contributes to the chilly climate experienced by underrep-

resented groups and factors into their decisions to leave science and academia. The brain drain caused by the reckless behavior of a select few, which is enabled by their peers, threatens individual careers and harms the collective, hindering scientific progress.

Harassment also sends the wrong message to junior scientists that such behavior is permissible in their research institution, reinforcing a culture in which one group can take advantage of another. Further, it sends the wrong message to the public in a time of political attacks on science.

In response to the recent sexual harassment cases, U.S. Rep. Jackie Speier (D-Calif.) recently addressed the U.S. Congress with plans to put forth legislation that would require universities to inform others of disciplinary proceedings regarding violations of Title IX, which protects people from discrimination based on sex in education programs that receive U.S. federal financial assistance (see <http://bit.ly/SpeierHouse>).

An Opportunity for Scientific Societies to Show Leadership

Where research institutions are failing, scientific societies have an opportunity—if not an obligation—to lead the way in transforming the culture of science into one that does not tolerate harassment.

This is especially important because harassment also occurs at meetings run by professional societies. For example, astronomers have created a grassroots network of allies on call to escort people from American Astronomical Society conference events safely, to protect attendees from other conferencegoers (see <http://bit.ly/AstroAllies>). This extraordinary model is being emulated by other scientific groups in response to harassment in their communities. That such networks need to exist is appalling.

Scientific societies should support these member-driven efforts and other initiatives to protect current and future generations of scientists from harassment. They should also use their positions of privilege to send a clear message that harassment will not be tolerated.

What Specifically Can AGU Do?

Facilitate public conversations about the problem. At the 2015 Fall Meeting, AGU leadership in collaboration with the Association for Women Geoscientists (AWG) and ESWN hosted a town hall session on the role of societies in responding to the problem of harassment (see <http://bit.ly/AGUSHTownhall>). The invited speakers were Meg Urry, professor of physics and astronomy at Yale University and president of the American Astronomical Society; Christine Williams, professor of sociology

at the University of Texas at Austin and an expert on gender, race, class inequality, and harassment in the workplace; and Mary Anne Holmes, professor emerita of Earth and atmospheric sciences at the University of Nebraska–Lincoln and past program director of the U.S. National Science Foundation’s (NSF) Increasing the Participation and Advancement of Women in Academic Science and Engineering Careers (ADVANCE) program.

The participation of AGU Past President Carol Finn, President Margaret Leinen, and President-Elect Eric Davidson sent a strong message that AGU takes the safety of its members seriously. This was the first of what we hope will be many public discussions on the problem and engagement with



Signage displayed throughout the conference center at the 2016 American Astronomical Society annual meeting.

members for feedback through other town halls, organized sessions, webinars, publications, and social media communications.

Codify a no-tolerance culture. Scientific societies have the responsibility to represent their members and the power to make a clear statement about what behaviors will not be tolerated. The American Astronomical Society has an antiharassment policy that defines sexual harassment as “unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature.” Their policy outlines processes for reporting, investigating, disciplinary action, and appeals.

AGU is currently reviewing its code of ethics in consultation with other societies and community and organization leaders. This code should also include strong language protecting those who report and assist in investigations from retaliation, and it needs to be prominent on the AGU website and communicated to its members regularly.

Enforce the code of ethics. Scientific societies can lead where academic institutions are failing. AGU should investigate all reported cases of violations that involve their members, whether they occur at AGU-sanctioned events or not. Disciplinary actions could

include the temporary or permanent loss of membership privileges, including participation at AGU-sponsored events, and revocation of bestowed honors and awards.

The American Association for the Advancement of Science recently withdrew the nomination of a scientist for one of its awards once it was revealed that he had pending criminal felony charges. Sanctions with real professional consequences send a deterrent message to potential violators and a clear message of support to victims.

Furthermore, we hope that when societies that contribute to the recognition of academic scientists publicly acknowledge that serial harassers damage the integrity of science and are a menace to our community, funding agencies will follow suit and force academic institutions to change their culture.

In January, NASA and NSF released statements on their policies against harassment and other types of discrimination (see http://bit.ly/NASA_SH and http://bit.ly/NSF_SH); this is an important first step to not allowing harassers or the institutions that protect them access to public grant funds.

Train personnel on best practices to respond to instances of harassment. The Astronomy Allies and the EntoAllies, the latter a grassroots effort from the entomological community, are examples of groups that can be created to ensure the safety of members at scientific meetings. AWG, ESWN, and other organizations that serve underrepresented groups also provide peer support to vulnerable communities.

In addition to supporting these types of grassroots efforts, which rely mostly on volunteer work, and considering the creation of its own “allies” group, AGU should go further and facilitate the training of AGU personnel and community leaders for effective responses to harassment.

Provide access to legal advice. AGU partners with organizations to provide free legal counseling to its members faced with intimidation and litigation for climate change research. AGU can take this a step further and provide the same access to legal advice for victims of sexual harassment.

Harassment of any kind endangers the ability of science professionals to conduct their work. Given the lack of support from academic institutions, AGU should lead.

Conduct research on the extent of harassment in the geosciences. The prevalence of harassment in our fields is unknown because the harassed are intimidated into not speaking out for fear of retaliation. As the largest geoscience professional society, AGU can lead the commission of a research survey of its membership in collaboration with other U.S.

Meg Urry

and international societies to collect information on the work culture of geoscientists.

AGU Needs to Lead

AGU leadership has made a public commitment to lead efforts to provide a safe and welcoming environment for all scientists (see <http://bit.ly/AGUProw>). We commend AGU for striving to find better ways to achieve its core guiding principles, which include equality and inclusiveness, building a space for diverse backgrounds, fostering open exchange of ideas, nurturing the next generation of scientists, and pursuing excellence and integrity in its mission to promote discovery in Earth and space science for the benefit of humanity.

Combating sexual harassment and other types of discrimination based on sex, gender, race, class, and ability is well within AGU's core guiding principles. We hope that AGU will approach changing the culture of our science with the same focus that underpins its other endeavors.

Acknowledgments

We thank the speakers at the town hall session "Forward Focused Ethics—What is the Role of Scientific Societies in Responding to

Harassment and Other Workplace Climate Issues?" The opinions expressed in this article represent those of the authors and not those of their employers or of AGU.

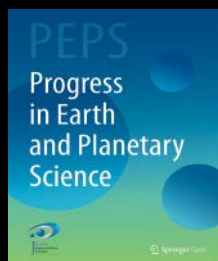
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By **Erika Marín-Spiotta**, Department of Geography, University of Wisconsin–Madison,

Madison; email: marinspiotta@wisc.edu; **Blair Schneider**, Department of Geology, University of Kansas, Lawrence; and **Mary Anne Holmes** (emeritus), Department of Earth and Atmospheric Sciences, University of Nebraska–Lincoln, Lincoln

Editor's Note: Marín-Spiotta is a leadership board member and diversity officer of the Earth Science Women's Network and past coprincipal investigator of an NSF ADVANCE PAID award, Collaborative Research: Career advancement for women through the Earth Science Women's Network. Schneider is president of the Association for Women Geoscientists. Holmes is coauthor of Women in the Geosciences: Practical, Positive Practices Toward Parity, the past director of the University of Nebraska–Lincoln's ADVANCE program (2008–2013), and the past program director for NSF's ADVANCE program (2014). A recording of AGU's 2015 Fall Meeting town hall session "Forward Focused Ethics—What is the Role of Scientific Societies in Responding to Harassment and Other Workplace Climate Issues?" is available through AGU On-Demand.



Open Access E-Journal PEPS

The Japan Geoscience Union (JpGU) would like to introduce its new peer reviewed English language open access e-journal Progress in Earth and Planetary Science (PEPS), which has been published by the JpGU and Springer since April 2014. PEPS prints original research articles and high quality review articles covering all of the fields of Earth and Planetary Science, including:

- Space and planetary sciences
- Atmospheric and hydrospheric sciences
- Human geosciences
- Solid earth sciences
- Biogeosciences.

It also welcomes papers based on interdisciplinary research.

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Progress in Earth and Planetary Science (PEPS)

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The Case for Multiuser Facilities

In the past 5 years, the National Academy of Sciences has released important decadal surveys that have far-reaching implications on federal funding of existing and future large facilities in the fields of astronomy, space physics, and ocean science. Faced with constrained and possibly decreasing budgets, federal agencies struggle to implement the important recommendations contained in these community-based documents. Unsurprisingly, they are looking carefully at current and future funding for their existing large facilities.

Funding for large facilities is perhaps the easiest target for budget cuts. Facilities are expensive, and oversimplified or misguided metrics of costs versus benefits promote an idea of bloat and waste. This can lead to a tunnel vision approach to budget reductions with a lopsided focus on large existing facilities.

The actual situation is more nuanced. Decisions regarding longstanding facilities must be made only after careful consideration of all possible impacts on the scientific enterprise because these facilities provide observing platforms, data streams, and educational assets for multiple users. We must also keep in mind that discoveries in geospace, as in astronomy and many other scientific fields, are driven by breakthrough observations, and many of these observations are made possible only by large, powerful facilities.

To ensure a balanced and fair outcome, the research communities must continue to be fully engaged in funding decisions by providing objective and thoughtful input to relevant agencies.

Facilities Versus Research Costs in National Science Foundation Divisions

The Astronomy Decadal Survey *New Worlds, New Horizons in Astronomy and Astrophysics* [National Research Council, 2010] resulted in a comprehensive portfolio review by the National Science Foundation's (NSF) Division of Astronomical Sciences (AST). The portfolio review committee was asked to "examine the balance across the entire portfolio of activities" and "maximize progress on the compelling science" described in the report by "balancing the recommendations for new facilities, instrumentation and programmatic enhancements with the capabilities enabled by existing facilities, grants programs, and other supported activities." AST is currently

implementing the recommendations of the portfolio review by evaluating the past and future effectiveness of several long-standing observatories.

Similarly, the Ocean Science Decadal Survey *Sea Change: 2015–2025 Decadal Survey of Ocean Sciences* [National Research Council, 2015] recommended rebalancing the funding in NSF's Division of Ocean Sciences between facilities and grants to best accomplish its science goals. Subsequently, on 11 May 2015, NSF committed to diverting ocean science funding from facility support to individual investigator awards.

Currently, the Geospace Section within NSF's Division of Atmospheric and Geospace Sciences, which supports the bulk of NSF-supported space physics research, is conducting its own portfolio review in order to create a funding wedge to implement the recommendations of the Solar and Space Physics Decadal Survey *Solar and Space Physics: A Science for a Technological Society* [National Research Council, 2013]. This portfolio review will inevitably be faced with the same problem of determining the appropriate balance between facility support and individual investigator awards.

At the highest level, NSF investment in facilities adheres to National Science Board guidance that it should remain within a range of 22% to 27% of the agency budget. However, the fractional investment in facilities supported by different NSF divisions can vary greatly. Figure 1 shows the relative level of funding for facilities in selected NSF divisions, according to the 2012 facilities portfolio review by the National Science Board's Subcommittee on Facilities [National Science Board, 2012]. Figure 1 demonstrates the wide range of facility support within different disciplines.

Clearly, some research areas are more dependent on facilities than others.

How Can We Gauge the Value of Facilities?

In the absence of an optimum proportion of facility funding that could be applied to all disciplines, communities must establish their own criteria for gauging the appropriate level of facility support. Given that facilities are intricately woven into the fabric of research communities, any criteria need to capture all the potential impacts.

The facilities supported by NSF's Geospace Section represent an excellent case study for evaluating how to allocate costs. Already operating under reduced budgets, facilities that could face cuts include incoherent scatter radars, a global array of upper atmospheric lidars, and the high-frequency Super Dual Auroral Radar Network (SuperDARN), as well as the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE), a program that makes use of data from the Iridium satellite constellation. The funding level for facilities in the Geospace Section has historically been between 30% and 35% of its total budget. As with all estimates of facility investments, these percentages include a significant amount of funding for staff scientists beyond the direct costs of maintaining operations, but they still serve to elucidate investment trends over time.

Most important for determining the appropriate level of funding for facilities is to quantify the science they support. Facilities are instructed to keep careful records of



Puerto Rico's iconic Arecibo Observatory has been struggling under reduced budgets and threats of further cuts that would require mothballing or closing the facility. The observatory, used for ionospheric, planetary radar and radio astronomy studies as well as monitoring near-Earth asteroids, is trying to diversify its support base to offset future reductions.

the number of users, the experiments conducted, the number of hours of operations, the publications resulting from facility data, and other metrics needed to assess true scientific value. Scientific leadership is also important and can be measured by the extent to which facilities and facility scientists are involved in community-based activities and remain at the cutting edge of research in their respective areas.

Another metric for determining whether a discipline has a healthy ratio of facility support is whether such support has inhibited the initiation of new programs. For instance, over the past 20 years, the Geospace Section has maintained facility funding at nearly constant levels while simultaneously initiating many high-priority community-driven activities. Examples include proposal opportunities for space weather, incentives for research institutions to develop faculty positions in space sciences, and the development and launch of cubesats, all of which were carved from existing budgets without additional funding over inflation.

The current network of geospace facilities has been developed over many years on the basis of the observational needs of a research area that is truly global. The recent recognition that the geospace and heliophysics domains are intimately linked makes it necessary to have comprehensive, global measurements.

In other disciplines, the new facilities have enhanced capabilities over those that are being replaced. That is not the case for geospace facilities. Loss of facilities creates gaps in global observational capabilities. Although relying on foreign partners to fill these gaps is a tempting strategy, there will be a cost, both financially and politically, for U.S. access to facilities operated by other countries. Such a reliance on foreign partners represents a strategic movement in a direction that federal agencies should consider very carefully.

Facilities Do More Than Generate Data

For NSF's Geospace Section, facilities do far more than provide data and observational support for "nonfacility" scientists. To be effective, each facility depends on some level of internal scientific effort to maintain and develop its capabilities.

If funds in geospace were to be shifted from facilities to the grants programs, these facility scientists would almost certainly write proposals and request funding in competition with other space science researchers. Having these scientists compete on an equal basis with others certainly has a great deal of merit, but in the overall financial picture it will most likely result in only limited cost savings. How much science support versus operational support should exist at each facility is complex and requires a careful study all by itself.

Other considerations in assessing the level of facility support include the role facilities play in supporting large national programs. For example, the geospace facilities play a key

experience for undergraduate programs, where students have an opportunity to have hands-on exposure to world-class instruments. An additional, less quantifiable factor is inspiration. What is the value, for example, of having more than 80,000 Puerto Rican schoolchildren each year gaze at, and be inspired by, the giant antenna at the Arecibo Observatory? We think it is immense, but such achievements are often neglected in assessing the value of a facility.

The Danger of Diverting Funds Away from Facilities

For the Geospace Section, the undeniable value of the facilities makes any reductions in the facility budgets risky. It is certainly true that some cost savings in the facility operating costs through consolidation of effort, partnerships with industry, and perhaps increased funding from other agencies should be possible. These are ongoing efforts that have worked extremely well in the past.

The case for geospace facilities is illustrative of similar challenges being faced by other disciplines that rely heavily on continually improving observational capabilities. Admittedly, not everything can be continued at present funding levels, but reductions should be based on meaningful criteria applied across all disciplinary investments while also minimizing any disruptive impact to ongoing science efforts.

Sunsetting of existing facilities that still have scientific value should be made only after thorough exploration of all possible funding alternatives. The

scientific community must be steadfast in seeking solutions that strengthen, rather than weaken, the overall research enterprise.

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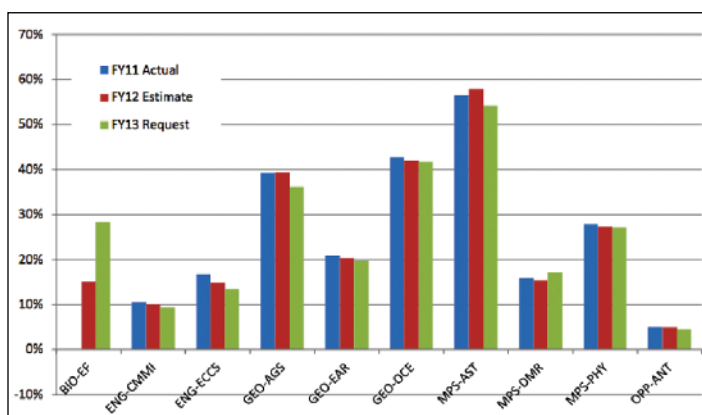


Fig. 1. Research infrastructure costs for selected National Science Foundation divisions as a percentage of division budgets. Divisions represented are Emerging Frontiers (EF) from the Directorate for Biological Sciences (BIO); Civil, Mechanical, and Manufacturing Innovation (CMMI) and Electrical, Communications and Cyber Systems (ECCS) from the Directorate for Engineering (ENG); Atmospheric and Geospace Sciences (AGS), Earth Sciences (EAR), and Ocean Sciences (OCE) from the Directorate for Geosciences (GEO); and Astronomical Sciences (AST), Materials Research (DMR), and Physics (PHY) from the Directorate for Mathematical and Physical Sciences (MPS). Also shown is the Antarctic (ANT) program of what was then known as the Office of Polar Programs (OPP). From National Science Board [2012].

role in the high-priority scientific research enabled by NASA missions, including the current Magnetospheric Multiscale (MMS) and Van Allen Probes satellite programs and the future Ionospheric Connection Explorer (ICON) and Global-Scale Observations of the Limb and Disk (GOLD) missions.

Similarly, facilities support the education of young scientists and public outreach. The NSF geospace facilities have provided data and observations used for many master's and doctoral dissertations. It is hard to imagine a thesis topic in geospace science that wouldn't benefit from the availability of data from one or more of the geospace facilities.

The facilities also provide a home base for important summer schools and research

By **Richard Behnke**, SciencePrime, LLC, Arlington Va.; email: behnke@science-prime.com; and **Robert Robinson**, InSpace, Inc., Arlington, Va.



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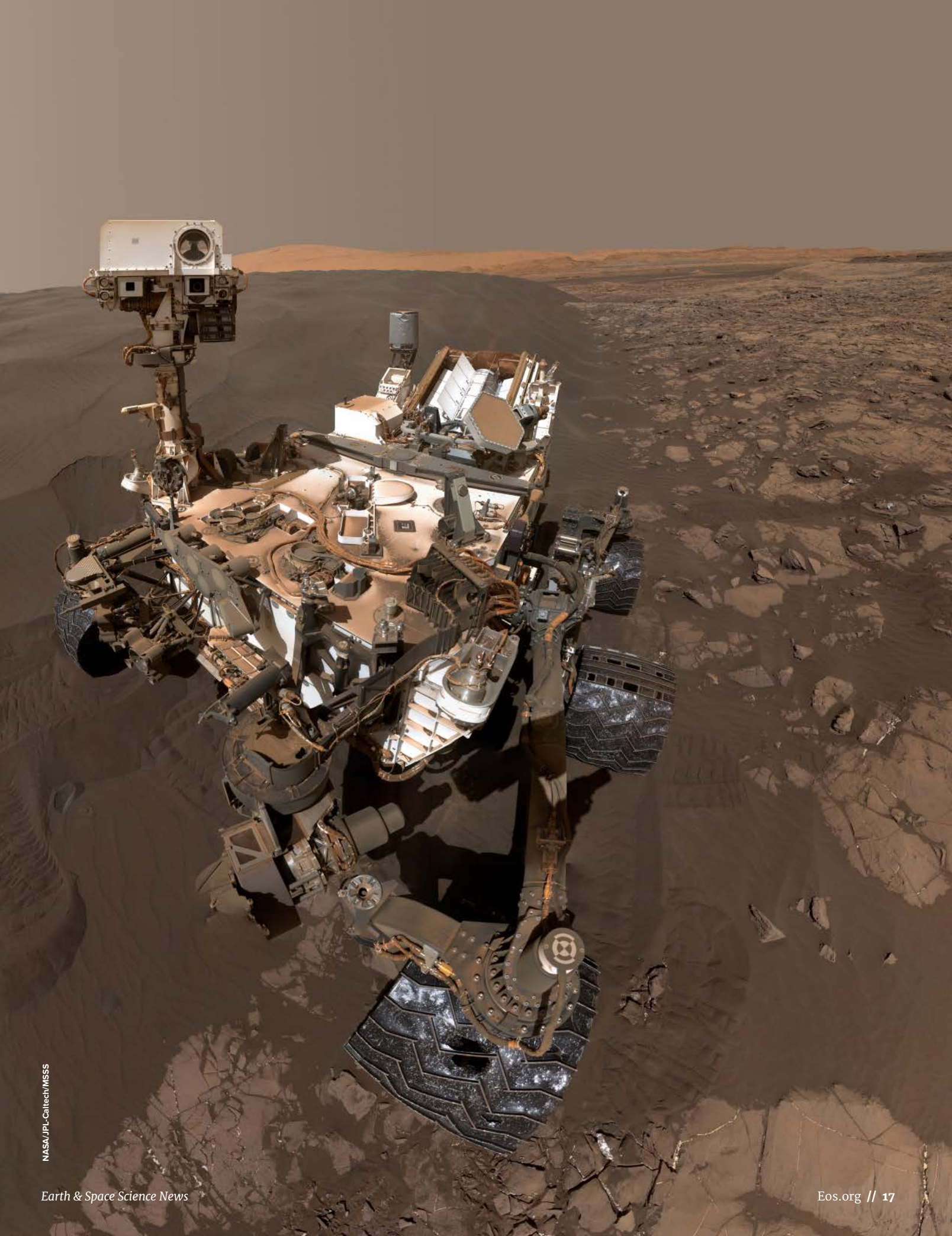
WHERE **CURIOSITY** HAS TAKEN US

By Ashwin R. Vasavada

“**T**ime to see where our Curiosity will take us.” Those were the words of Flight Controller Allen Chen as NASA’s Mars rover Curiosity touched down in August 2012. The dramatic landing was a success in its own right, demonstrating a new system in which a rocket-powered “skycrane” lowered the 1-ton rover to the surface of Mars within just 2.5 kilometers of its target. But it also marked the beginning of a rich and exciting scientific journey focused on revealing the habitability of ancient Mars.

The Mars Science Laboratory (MSL) mission [Grotzinger *et al.*, 2012; Grotzinger *et al.*, 2015a], with its Curiosity rover (Figure 1), was conceived as a mobile geochemical laboratory. For the past

The Curiosity rover, one of NASA’s flagship missions, analyzes Martian geology, geochemistry, climatology, and radiation to assess whether Mars could have supported microbial life.





NASA/JPL-Caltech/MSSS

A panorama of images taken by NASA's Mars rover Curiosity's mast camera on 25 September 2015 shows the Bagnold Dunes (dark band at bottom), looking toward the northwest flank of Aeolis Mons (Mount Sharp). The rounded buttes at the center contain sulfates, a possible indicator of volcanic activity and a lack of water during their formation. The rugged, pale bedrock visible at the upper half of the mountain is likely composed of Martian dust. Colors have been balanced to resemble how the rocks and sand would appear under daytime lighting conditions on Earth.

3.5 years, the rover has traversed the rugged terrain of Gale Crater, carrying out its chief objective: to quantitatively assess whether early Mars could have supported microbial life.

To do so, Curiosity looked for geologic and environmental clues to determine the availability and chemistry of water, the presence of carbon and other key elements required by life, sources of energy that could sustain metabolism, and the absence of chemical or environmental hazards.

A Mobile Martian Laboratory

In 2004, NASA selected a payload of 10 instruments designed to accomplish these challenging analytical measurements, as well as the geological field work necessary to uncover the ancient history of the environment. These instruments include high-definition imagers; a laser-induced breakdown spectrometer that carries out point chemical analyses; a neutron spectrometer that measures hydrogen abundance; an X-ray spectrometer mounted to the arm that can perform bulk elemental analyses; an X-ray diffractometer that can analyze mineralogy; and a combined mass spectrometer, gas chromatograph, and tunable laser spectrometer (GCMS-TLS) that analyzes volatiles, isotopes, redox states, and organic carbon.

Altogether, Curiosity's payload allows it to carry out the first comprehensive chemical and mineralogical descriptions of Martian surface materials. The payload and the

science team that oversees it are distinctly international, with three instruments and parts of others provided by Canada, Russia, Spain, France, Germany, and Finland. Forty percent of the mission's nearly 500 science team members are based outside of the United States.

NASA chose the mission's landing site through a multiyear study by the MSL project and members of the Mars and terrestrial science communities. After scrutinizing the scientific value and safety characteristics of 60 candidate sites, the study settled on Gale Crater. The 154-kilometer-diameter crater contains a 5-kilometer-high central mound of stratified, sedimentary rock named Aeolis Mons (informally called Mount Sharp).

Satellite imagery appears to show numerous water-shaped landscapes, and spectroscopy has revealed iron oxide, clays, and sulfates—mineralogy that occurs when

The geology and geochemistry reveal an ancient environment at Yellowknife Bay that would have been habitable to simple forms of life.

water and rock interact. The extensive and variable stratigraphic record offers Curiosity the chance to explore multiple potentially habitable environments, with the additional and important opportunity to derive key environmental transitions from the geologic record.

Yellowknife Bay: An Ancient Martian Habitat

Curiosity carried out its first in-depth investigation at Yellowknife Bay, an expanse of bedrock forming the outer edge of a fan of debris that appears to have been deposited by an ancient river flowing from the northern crater rim. En route, the rover came across outcrops that were

clearly formed by flowing water, consisting of rounded pebbles cemented together like river sediment.

The team hypothesized that the fine-grained mudstone at Yellowknife Bay formed within an ancient lake bed and chose it for the rover's initial drilling campaign. Although its elemental makeup mirrored that of typical Martian soil, X-ray diffraction revealed that the sample also contained roughly 20% smectite clay minerals, indicating that fresh water, low in acidity, had altered it. The laboratories also discovered both reduced and oxidized forms of sulfur—a potential energy source for some kinds of microbes.

After further lab work on both Mars and Earth, the team announced the trace detection of the organic molecule chlorobenzene, thought to form via the interaction of indigenous Martian organic molecules and oxychlorine compounds that are widely distributed on Mars [Freissinet *et al.*, 2015]. The team also found nitrates that had formed within the Martian environment, a discovery of paramount importance for habitability, given their centrality to biology and the large amounts of energy required for natural processes to convert elemental nitrogen to this usable form. Together, the geology and geochemistry reveal an ancient environment at Yellowknife Bay that would have been habitable to simple forms of life.

Finally, using a technique conceived after landing, Curiosity determined the history of the Yellowknife mudstone using two types of indicators. First, it was able to measure when the rock's grains originally crystallized through radiometric dating—examining the number of atoms that have radioactively decayed over time. Second, it was also able to determine how long the rock sat exposed on the surface of Mars by measuring the beating it took from powerful cosmic rays, which can knock out a proton or neutron from an atom and transform it into different elements or isotopes.

The latter indicator revealed that the rock had been exposed only about 80 million years ago and had been uncovered by wind-driven erosion. That information suggests a strategy for future Mars missions—exploring recently eroded terrain to access sites where organic molecules and other biomarkers have experienced less degradation from surface chemistry and radiation.

Additional geochemical findings along the rover's 12-kilometer traverse include sediments and some igneous rock fragments rich in feldspar, suggesting a crustal composition that is more chemically evolved than



NASA's Curiosity Mars rover took this "selfie" on lower Mount Sharp, where it drilled into the "Buckskin" rock target. This image is a composite of several photographs taken on 5 August 2015.

expected [Sautter *et al.*, 2015]. Widespread features called veins and concretions—which form in the presence of water—indicate that water interacted with the bedrock multiple times, with different chemical compositions.

With river and lake sediments dominating the traverse, the team is currently piecing together the story of the formation of Aeolis Mons itself. Lakes may have filled Gale Crater multiple times, depositing the sediment that formed the lower layers of Aeolis Mons, which would imply a long-lived warm and wet climate [Grotzinger *et al.*, 2015b].

Exploring the Ancient and Modern Atmosphere

Curiosity has also found clues about Mars's primeval habitability in the present-day atmosphere by measuring the abundances of each isotope for a given element. This measurement relies on the principle that as a planetary atmosphere escapes into space, the lighter isotopes are lost more readily. As this goes on, the relative abundances of the heavier isotopes rise beyond their primordial values.

On Mars, the isotopic compositions of the noble gases, as well as carbon dioxide, nitrogen gas, and water, are all unusually heavy. These results support the idea that most of the Martian atmosphere has been lost to space and much of its surface water has escaped in the form of water



NASA/JPL-Caltech/MSSS

Fig. 2. Darker, cross-bedded sandstones such as those shown here lie above the fine-grained mudstones that form the basal layer of Aeolis Mons. Higher levels of the western flank of the mountain appear in the background. Curiosity took the images in this mosaic on sol 1003 (2 June 2015).

vapor. Curiosity found that the proportion of heavy water—in which some of the hydrogen atoms have an extra neutron—in clay minerals at Yellowknife Bay lies midway between the primordial and present-day values. These clay minerals formed more than 3 billion years ago, indicating that even by then, Mars had lost a substantial amount of its atmosphere [Mahaffy *et al.*, 2015].

There are also tantalizing results from a campaign of monitoring methane in Mars's atmosphere. Observations show a background amount (about 1 part per billion by volume), consistent with ongoing production from organic materials delivered by exogenous dust and impactors. The team cannot yet explain a brief period lasting about 60 Martian days in early 2014 when the methane content increased tenfold.

Even while focused on exploring the ancient history of Gale Crater, Curiosity has carried out an unprecedented in situ study of the weather and climate of modern Mars. The rover's meteorology station has gathered a nearly

continuous hourly record of atmospheric pressure, ground and air temperature, solar ultraviolet flux, relative humidity, and wind. The rover's cameras can measure dust in the atmosphere while the mast-mounted spectrometer can sense water vapor.

The data show that Curiosity's location within a deep impact crater and downslope from both the crater rim and central mound amplifies the tidal waves of atmospheric pressure that sweep across Mars as a result of solar heating. The team has detected dust-devil-like vortices in the pressure data but hasn't observed any because convection that would otherwise lift dust is counteracted by downdrafts driven by the crater topography.

Curiosity's radiation detector has been taking measurements that will be crucial to understanding the hazards that astronauts will face on Mars from powerful galactic cosmic rays and the energetic particles that the Sun emits during solar storms. These first measurements from the surface reveal just how much of that radiation Mars's atmosphere blocks and how many secondary particles form, both of which are critical inputs for understanding the risk to crews on future missions.

Onward and Upward

As one of NASA's flagship missions, Curiosity has demonstrated a breadth and depth of scientific investigation not possible with lower-cost missions. Results from Curiosity have fundamentally advanced our understanding of Mars over a broad range of disciplines, including astrobiology, geology, geochemistry, planetary evolution, paleoclimate, modern weather and climate, and space physics. The rover and its tools for imaging from kilometer to micrometer scales have enabled exceptional field geology, with the rover examining the stratigraphy and sedimentology of outcrops (Figure 2) to tease out their history. The mission's geochemical discoveries required onboard laboratories capable of running multiple analyses on each sample with varying experimental protocols and calibration techniques.

The rover journeys on with a healthy payload and much left to explore. Over the next few years, the rover will examine a large, active dune field; traverse an

Curiosity's radiation detector has been taking measurements that will be crucial to understanding the hazards that astronauts will face on Mars.

extensive ridge enriched in iron oxide; explore a region on Aeolis Mons where orbiting satellites have detected clay minerals; and ascend the slopes of Aeolis Mons until it reaches a layer where sulfate minerals are present, perhaps signifying a more sulfur-rich and arid environment when these materials formed. Let's see where Curiosity takes us; we can be sure that surprises await.

A full list of publications is available at the Mars Science Laboratory website (see http://bit.ly/Mars_Lab).

Acknowledgments

The MSL Science Team is greatly indebted to the MSL operations, engineering, and management teams at the Jet Propulsion Laboratory. Part of the research described in this article was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by NASA.

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Author Information

Ashwin R. Vasavada, Jet Propulsion Laboratory, California Institute of Technology, Pasadena; email: ashwin.vasavada@jpl.nasa.gov

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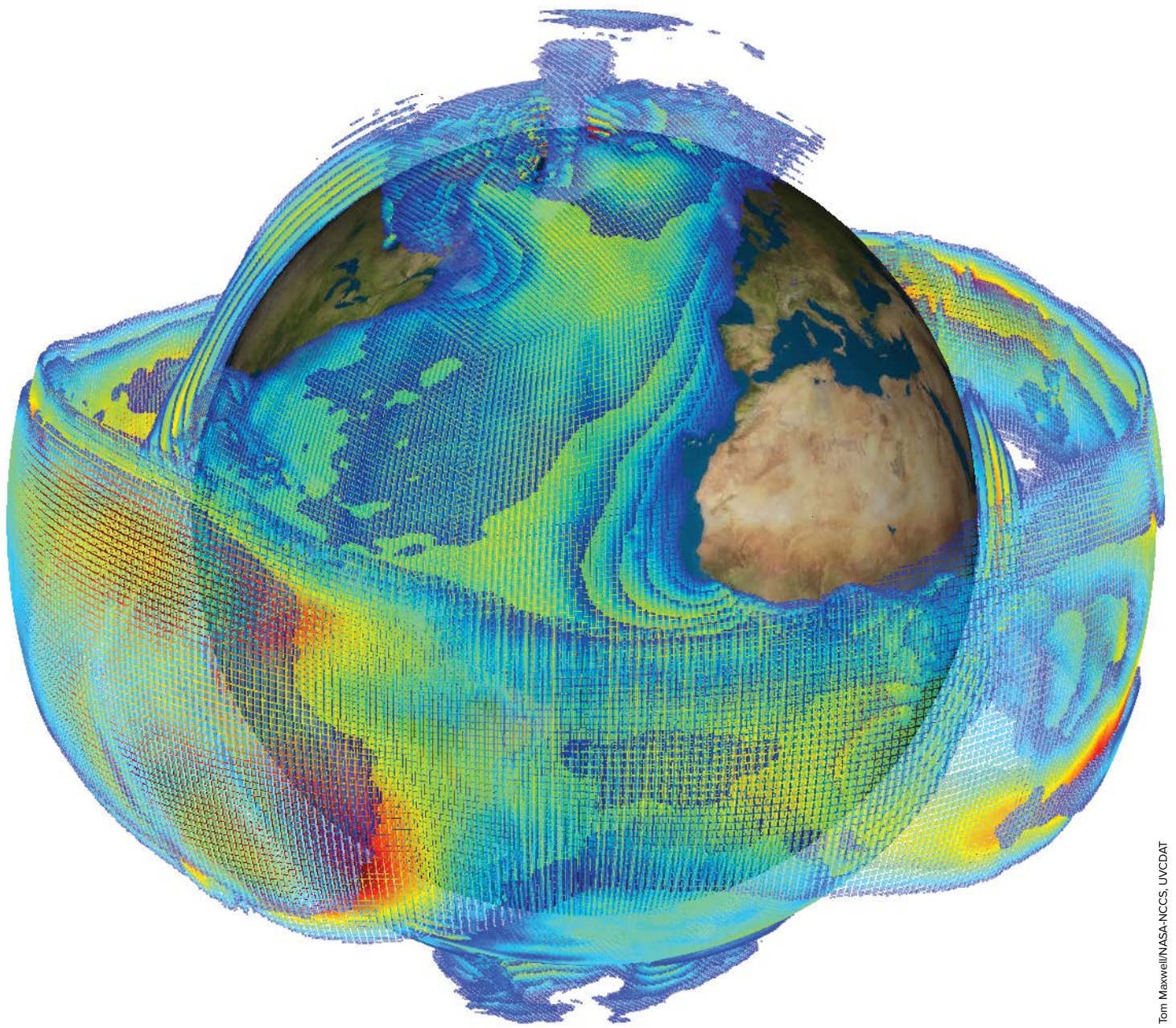
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 **AGU PUBLICATIONS**



Tom Maxwell/NASA-NCCS, UVCDAT

Better Tools to Build Better Climate Models

By Dean N. Williams

A Department of Energy collaboration aims to make climate model development faster and more efficient by creating a prototype of a system for testing model components.

Developing, maintaining, and enhancing a predictive climate model demand enormous human and computing resources. Decades' worth of observational data must be compiled, vetted, and integrated into a database. Parameters and variables must be identified and built into algorithms that simulate physical processes. Massive calculations can then convert past observations into predictions of the future.

To determine the accuracy of predictions, results are validated by comparing them to present-day observations. As new data are fed to the model and scientific understanding of climate systems evolves, new information gets built into the model, and the testing and validation continue.

One of the most resource-intensive aspects of climate modeling is the creation of a system for calibrating climate models, where model simulations are used to validate model output against observational data sets that span the globe. We call this system a "climate model test bed." Such test bed environments typically evaluate each component of the model in isolation, using a skeleton framework that makes the module behave as if it were functioning within the larger program.

To calibrate the model against regional observational data sets, uncertainty quantification techniques assess the accuracy of predictions, given the limitations inherent in the input information.

If model developers could compare test bed output to observational measurements as the output was being generated, the comparison could facilitate aligning the model with the observed data. This capability could eliminate some of the more tedious activities associated with model development and evaluation.

Researchers from five Department of Energy (DOE) laboratories are currently developing this real-time compari-

son capability. If successful, the capability could accelerate the development of climate submodel components, such as atmosphere, land, ocean, and sea ice. It could also improve the process by which the submodels are integrated with one another to form the resulting coupled Earth system climate model.

Leveraging Tools and Building Collaborations

For this effort, which began in mid-2011, the test bed developers fed representative observational data sets—for example, satellite data from NASA's Atmospheric Infrared Sounder (AIRS) and Clouds and the Earth's Radiant Energy System (CERES)—into the specialized model testing and verification platform that they developed. This prototype platform allows for the rapid evaluation of model components and algorithms. A broad goal is to enhance predictive capabilities through the DOE's Biological and Environmental Research (BER) Climate Science for a Sustainable Energy Future (CSSEF) project, which was the sponsor of this work.

Over the past several years, CSSEF team members have collaborated extensively with national and international institutions, universities, and private companies that specialize in data-intensive science and exascale computing to advance scientific model development and evaluation by leveraging state-of-the-art tools. CSSEF's Testbed and Data Infrastructure (TDI) subteam has also worked closely with climate scientists to develop and refine the tools for evaluating model components.

To build the test bed prototype, the CSSEF team has employed DOE's high-performance computing resources to make use of several open-source software projects that are steadily gaining recognition and usage in their respective research communities. In particular, the test bed prototype uses the distributed data archival and retrieval system established under the Earth System Grid Federation [Williams

A three-dimensional view of relative humidity from the surface to an altitude of about 3 kilometers, made using data from the Community Atmosphere Model (CAM). Red represents air parcels at maximum humidity—more water added to the system would cause precipitation. Blue means that an air parcel is 75% of the maximum. Values below 75% are transparent. Height above the Earth is expanded for visibility.

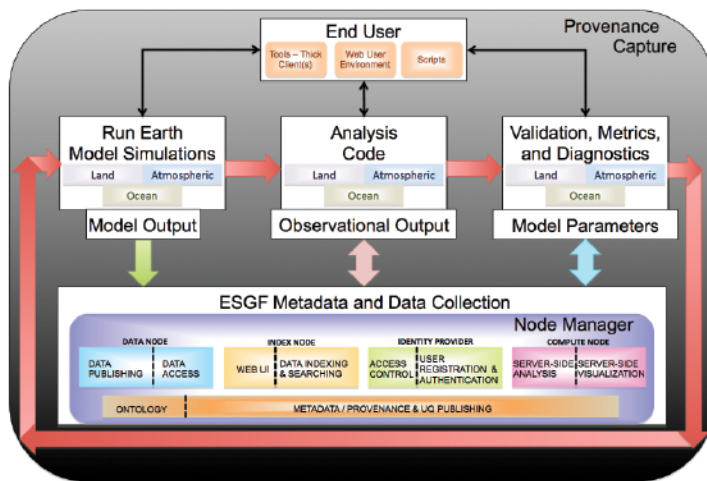


Fig. 1. A high-level conceptual view of the U.S. Department of Energy's Climate Science for a Sustainable Energy Future (CSSEF) test bed architecture and workflow with provenance capture. The red arrows show the baseline ensemble loop in which model simulations are conducted using a variety of input parameters generated by metrics and ensemble drivers. At any stage, data can be collected and stored in the Earth System Grid Federation (ESGF) distributed archive. The black arrows show where desktop clients, Web browsers, or scripts gain access and control the test bed. UI is user interface, and UQ is uncertainty quantification.

et al., 2016] and the Ultrascale Visualization Climate Data Analysis Tools framework [Williams, 2014]. Existing exploratory analysis tools for these databases are also accessible from a Web browser [Steed et al., 2013], allowing the test bed to easily handle incoming data.

The tools and experience resulting from these DOE-sponsored projects provide the foundation for the prototype test bed's infrastructure. Now, through the integration of existing technologies, open standards, and community expertise, the CSSEF team has unveiled a unique and flexible prototype that it hopes will accelerate the development of future climate models.

Incorporating Powerful Provenance Capability

The prototype includes integrated workflows and capabilities for evaluating model provenance, running diagnostics, and examining data analysis and visualization. It also includes automated testing and evaluation.

Provenance, in this context, is the details concerning the setup, execution, and analysis of the model. The test bed prototype captures and archives this information. It also standardizes metadata creation and annotation, and it provides forums for group discussion and sharing. Provenance is of particular interest because it increases scientific and experimental reproducibility, repeatability, productivity, and credibility of collaboration.


CSSEF uses the Provenance Environment (ProvEn) framework for the test bed prototype [Stephan et al., 2013]. Once it is fully imple-

The team has unveiled a unique and flexible prototype that it hopes will accelerate the development of future climate models.

mented within the test bed, ProvEn will provide comprehensive services for the collection and storage of processing provenance including published metadata.

ProvEn correlates computational provenance with knowledge provenance—i.e., newly formed understandings gained from the integration of disparate information—to help scientists browse data, as well as infer and question conclusions. ProvEn will also help scientists mix simulations with observa-

Vienna University of Technology



Vienna Doctoral Programme on Water Resource Systems

The Centre for Water Resource Systems at the Vienna University of Technology announces competition for the third intake of doctoral candidates for the Doctoral Programme on Water Resource Systems. The programme is anticipated to host a total of 70 doctoral students over a period of 12 years. This is a dedicated programme of the Austrian Science Fund (FWF) that promotes doctoral research and education at the highest standards and provides excellent opportunities for cross-disciplinary research. International networking is facilitated by a mobility programme with a spectrum of attractive international partner institutions and a comprehensive guest scientist programme.

Seven PhD student positions are available in the following research themes related to Water Resource Systems:

- Flood-hydrology
- Aquatic microbiology
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- Environmental economics
- Environmental engineering
- Soil moisture remote sensing
- Mechanics of structures

Applicants must have a Master's degree (or equivalent), preferably in a subject related to water resource systems. The working language of the programme is English. Students are expected to work across disciplines and in cooperation with others. A capacity and willingness to integrate and collaborate is essential.

The Programme provides a salary according to the FWF scheme (approx. EUR 20000/year net), together with health and social security benefits. There is also significant allowance for travel and research support. TU Wien is an equal opportunities employer. The preferred starting date is Oct. 1, 2016.

Candidates should send a letter of application, a statement of research interests, a Curriculum Vitae, and copies of education certificates including transcripts of grades as a single .pdf file to: office@waterresources.at.

Application deadline is April 30, 2016. Short listed candidates will be invited to a selection seminar. Financial support towards travel expenses is available on request.

Information about the Doctoral Programme on Water Resource Systems may be viewed at <http://waterresources.at>

An ensemble of temperature data from 23 climate models from phase 3 of the Coupled Model Intercomparison Project (CMIP3) archive, superimposed over a snippet of the standard world satellite map. Colors represent the average temperature change for the year 2080 compared to current conditions, with dark blue representing about a 1°C change and dark red representing about a 10°C change. Images like these are automatically generated by playing Lawrence Livermore National Laboratory's *Interactive Energy & Climate Simulation*, a product that undergoes constant evaluation and validation.

tions—through ProvEn, these very different data sets can be compared and harmonized so that the result can better refine models and calculations.

Adaptable Architecture

The CSSEF test bed architecture (Figure 1) allows users to run individual or groups of model components in isolation. The team designed the prototype test bed's infrastructure so that it could be easily customized to users' specific requirements, for example, to test models of ocean dynamics or land cover changes.

The prototype test bed analyzes climate model output and verifies it against observed data sets. Its user interface allows investigators to search and discover scientific data from the entire system (observations, model input, model output), browse data collection hierarchies, download and organize data collection files individually or in bulk, run model components, track deep storage file download requests, and access user profile information.

The CSSEF scientific community is studying the use of the Web browsers and client analysis tools in the prototype test bed, but the CSSEF team has noted the limitations of creating repeatable processes and provenance capturing. For example, multiple sharing of Web and other remote resources often slows the manipulation of data and the sharing of visualization results. Therefore, for Web browser interfaces and remote client analysis tools to work properly, workflow scripts must be well-defined, repetitive computational tasks that integrate existing applications according to a set of rules.

Development Continues Under New Banner

The prototype test bed team is now under the banner of the newly formed Accelerated Climate Modeling for Energy (ACME) project, under the auspices of the U.S. Department of Energy's Office of Science. Under ACME, the team will continue its efforts to deliver an advanced model development, testing, and execution workflow and data infrastructure production test bed for DOE climate and energy research needs. We anticipate rolling out the test bed by the end of 2016 for ACME use.

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The CSSEF test bed prototype was developed by many scientists from several institutions. They are Ian Foster, Rachana Ananthakrishnan, Eric Blau, and Lukasz Lacinski from Argonne National Laboratory; Renata McCoy, Jeff Painter, Elo Leung, Carla Hardy, Matthew Harris, Charles Doutriaux, and Tony Hoang from Lawrence Livermore National Laboratory; Galen Shipman, John Harney, Chad Steed, Brian Smith, Benjamin Mayer, Marcia Branstetter, and John Quigley from Oak Ridge National Laboratory; Kerstin Kleese-Van Dam, Zöe Guillen, Eric Stephan, and Carina Lansing from Pacific Northwest National Laboratory; and Cosmin Safta from Sandia National Laboratory. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344.

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Author Information

Dean N. Williams, Computation Division, Lawrence Livermore National Laboratory, Livermore, Calif.; email: williams13@llnl.gov

2017 Fall Meeting to Go to New Orleans, 2018 to Washington, D. C.



A street corner in the French Quarter of New Orleans. The 2017 AGU Fall Meeting will take place in New Orleans. The meeting will then move to Washington, D. C., for 2018.

AGU's Board of Directors voted last month to move the Fall Meeting out of San Francisco, Calif., for the next 2 years. In 2017, the meeting will take place in New Orleans, La., and then it will go to Washington, D. C., for 2018.

For this year, however, the meeting will remain in San Francisco, where it has been held for 48 years. AGU intends to offer the meeting there again in 2019, the scientific

26,000 attendees, including scientists, exhibitors, educators, press, and others.

"AGU's Fall Meeting is one of the most important events in the Earth and space science community each year, and its success over the last 5 decades has played an important role in advancing that science," Leinen said. "That's why the risk posed by the Moscone Center construction was not something that we could ignore."

society's centennial year, AGU officials announced in early February.

Massive renovations planned for Moscone Convention Center, the meeting's usual venue (see <http://bit.ly/Moscone-Renovates>), led to the decision to relocate, said AGU president Margaret Leinen, who is also director of the Scripps Institution of Oceanography in La Jolla, Calif. Last year, the conference attracted more than

working opportunities—convinced the organization's leaders that it was necessary to find an alternative location for those 2 years.

Only 10–12 cities in the United States offer the capacity, in terms of convention center space, abundance of nearby hotel rooms, and airline service, to handle such a large conference. The society requested proposals from eight of those cities, including San Francisco, AGU officials said.

AGU selected New Orleans for 2017 because the Big Easy, as the city is known, could house all of the presentations and other activities of the conference under the single roof of its vast convention center. Among other attractions, the city surpassed other venues in the number of hotel rooms within walking distance of the convention center and abounds in restaurants at a range of costs in close proximity to the meeting facilities.

"The risk posed by the Moscone Center construction was not something that we could ignore."

D. C. in 2018

Washington, D. C., rose to the top for the following year, 2018, because it can provide sufficient space for the Fall Meeting in its sprawling downtown convention center and nearby hotels. The lively, cultured capital city also stood out because of its many hotels across a range of room prices, an excellent public transit system, good dining, and other amenities. The presence of the U.S. federal government and AGU's headquarters in the city also boosted its desirability, AGU officials said.

Neither of the selected cities could house the meeting for both 2017 and 2018. Other conferences booked into New Orleans in 2018 were expected to limit hotel availability during AGU's preferred meeting dates during the first 3 weeks of December. Likewise, the year 2017 didn't pan out in Washington, D. C., because the city's convention space wasn't available during AGU's preferred dates.

A blog entry written by Leinen and other top AGU leaders and posted on 9 February on the organization's *From the Prow* blog gives more details about the Fall Meeting relocation (see <http://bit.ly/FTP-relocate>).

By **Peter L. Weiss**, Senior News Editor

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Construction Squeeze

Already under way on a modest scale last year, the construction will pose additional, but still manageable, challenges to the meeting this coming year, according to AGU. However, the more intense disruption expected from the overhaul in 2017 and 2018—ranging from displacing hundreds of presentations into many different hotels to a diminished scientific program and fewer net-

Outstanding Student Paper Awards

The following AGU members received Outstanding Student Paper Awards at the 2015 Fall Meeting in San Francisco, Calif. Winners have individual pages on AGU's website (see <https://membership.agu.org/ospa-winners/>).

Atmospheric and Space Electricity

Coordinator: Morris Cohen

Neal Dupree, University of Florida, *Oceanic lightning versus continental lightning: VLF peak current discrepancies*

Jackson McCormick, Georgia Institute of Technology, *X-ray solar flare induced ionospheric perturbations observed by VLF sferics*

Atmospheric Sciences

Coordinators: Shannon Capps, Sue Chen, Yongyun Hu, Roya Mortazavi

Sabour Baray, York University, *Quantifying sources of methane in the Alberta oil sands*

Quentin Coopman, University of Utah, University of Lille, *Effect of long-range aerosol transport on the microphysical properties of low-level clouds in the Arctic*

Khaled Ghannam, Duke University, *Closure of the heat flux budget with the ejection-sweep cycle in the convective atmospheric boundary layer*

Leah Grant, Colorado State University, *Cold pool and surface flux interactions in different environments*

Karl Lapo, University of Washington Seattle, *Evaluating patterns of solar irradiance errors over an area of complex topography*

Michael McClellan, Massachusetts Institute of Technology, *Measurement and modeling of site-specific nitrogen and oxygen isotopic composition of atmospheric nitrous oxide at Mace Head, Ireland*

Erin McDuffie, University of Colorado Boulder, *Toward a quantitative assessment of the influence of regional emission sources on ozone production in the Colorado Front Range*

Gergana Mouteva, University of California, Irvine, *Spatial and temporal variations of EC and OC aerosol combustion sources in a polluted metropolitan area*

Kyle Nardi, Temple University, *The climatology and impacts of atmospheric rivers near the coast of southern Alaska*

Peer Nowack, University of Cambridge, *Troposphere-stratosphere coupled chemistry-climate interactions: From global warming projections to air quality*

Steven R. Schill, University of California, San Diego, University of Wisconsin-Madison, *Development and application of a hygroscopicity basis set for the analysis of the mixing state of nascent sea spray aerosols*

Kate Skog, University of Wisconsin-Madison, *Formation of epoxide derived SOA and gas-phase acids through aqueous aerosol processing in the southeastern United States during SOAS*

Ivy Tan, Yale University, *Observational constraints on mixed-phase clouds imply higher climate sensitivity*

Alexander Teng, California Institute of Technology, *Isoprene peroxy radical dynamics: Constraints from laboratory studies*

Jordis Tradowsky, Free University of Berlin, *A site atmospheric state best estimate of temperature for Lauder, New Zealand*

Ian Philip White, University of Bath, *Dynamical response to the QBO in the northern winter stratosphere: Signatures in wave forcing and eddy fluxes of potential vorticity*

Wei Wu, University of Illinois at Urbana-Champaign, *Contrasting ice microphysical properties of wintertime frontal clouds and summertime convective clouds*

Lu Xu, Georgia Institute of Technology, *Ubiquitous presence of particle-phase organic nitrates in the southeastern United States*

Biogeosciences

Coordinator: Susan Natali

Kristofer Covey, Yale University, *Mapping tree density at the global scale*

Amanda D'Elia, University of California, Davis, *Deep carbon stocks in a California Delta floodplain: Evidence for long term sequestration potential of seasonally inundated soils*

Loïc Dutrieux, Wageningen University, *Reconstructing land use history from Landsat time-series. Case study of swidden agriculture intensification in Brazil*

Anne Griebel, University of Melbourne, *Effect of non-homogeneity in flux footprint on the interpretation of seasonal, annual, and interannual ecosystem carbon exchange*

Matthew Robert Hiatt, University of Texas at Austin, *River delta network hydraulic residence time distributions and their role in coastal nutrient biogeochemistry*

Tyler Hoecker, University of Montana, *Spatiotemporal trends in late-Holocene fire regimes in arctic and boreal Alaska*

Maria de los Angeles Gallego Mingo, University of Hawai'i at Mānoa, *Explaining two centers of $p\text{-CO}_2$ and CO_2 flux variability in the equatorial Pacific induced by ENSO*

Eugenie Paul-Limoges, ETH Swiss Federal Institute of Technology Zurich, *Contributions of understory and overstory to ecosystem CO_2 fluxes in a temperate mixed forest in Switzerland*

Victoria Scholl, Rochester Institute of Technology, *Assessing and adapting LiDAR-derived pit-free canopy height model algorithm for sites with varying vegetation structure*

Bingjie Shi, University of Waterloo, *Importance of tetrahedral iron during microbial reduction of clay mineral NAU-2*

Cryosphere

Coordinators: Elynn Enderlin, Kaitlin Keegan, Dan McGrath, Lucas Zoot

Ryan Cassotto, University of New Hampshire, *Large response to precipitation and tidal forcing at Columbia Glacier imaged with terrestrial radar interferometry*

Winnie Chu, Columbia University in the City of New York, *Extensive subglacial hydrological network and basal temperature layer in Southwest Greenland: An integrated approach of radar analysis and ice sheet modeling*

Luca Foresta, University of Edinburgh, *Mass balance of Icelandic ice caps from CryoSat swath mode altimetry*

Nicholas Holschuh, Pennsylvania State University, *Englacial structures as indicators of the controls on ice flow*

Felix Matt, University of Oslo, *Hydrological response to black carbon deposition in seasonally snow covered catchments in Norway using two different atmospheric transport models*

Brice Noel, Utrecht University, *A downscaled 1 km dataset of daily Greenland ice sheet surface mass balance components (1958-2014)*

Deepak Singh, University of Michigan, *Impact of dust on Mars surface albedo and energy flux with LMD general circulation model*

Donald Slater, University of Edinburgh, *Co-evolution of tidewater glacier calving front morphology and submarine melt rates in a high resolution ocean model*

Yvonne Smith, University of Leeds, *Exploring Northern Hemisphere ice sheet variability in the Pliocene using ice rafted debris records and iceberg trajectory modelling*

Earth and Planetary Surface Processes

Coordinators: Ken Ferrier, Xiaofeng Liu

Jonathan A. Czuba, University of Minnesota, Twin Cities, *Near-channel sediment sources now dominate in many agricultural landscapes: The emergence of river-network models to guide watershed management*

Jaap Nienhuis, Massachusetts Institute of Technology, *Wave-driven tidal inlet migration: Mechanics and effects on barrier morphology*

Laura Reynolds, University of California, Santa Barbara, *Dating historical sediments in estuaries: A multi-proxy approach*

Charles Shobe, University of Colorado Boulder, *Big blocks and river incision: A numerical modeling perspective*

Lauren Shumaker, Stanford University, *Constraining the formation of submarine gullies on continental slopes*

Matthew David Weber, University of California, Davis, *Fluvial change processes during an exceptional drought punctuated by atmospheric rivers*

Earth and Space Science Informatics

Coordinators: Mohamed Aly, Xiaogang Ma, Jonathan Petters, Som Sharma

James Ryan, University of Arizona, *EarthCubed: Community convergence and communication*

Education

Coordinator: Stacie Bender

John Leeman, Pennsylvania State University, *Podcasting as a medium to share STEAM fields*

Geodesy

Coordinators: Olivier de Viron, Rowena Lohman, Emily Montgomery-Brown

Stefanie Kaboth, Utrecht University, *Glacial-interglacial sea level reconstruction of the last 570 kyr: Inferences from a new benthic 18O record of IODP Site U1386 (Gulf of Cadiz)*

Hélène Le Mével, University of Wisconsin-Madison, *Magma injection models to quantify reservoir dynamics at Laguna del Maule volcanic field, Chile, between 2007 and 2015*

Patricia MacQueen, Colorado School of Mines, *Down conversion of ambient seismic noise as a tool to detect non-linearity and estimate instrument noise levels in a gravity meter*

Geomagnetism and Paleomagnetism

Coordinator: Julie Bowles

Annemarieke Béguin, Utrecht University, *Micromagnetic tomography in practice*

Anna Mittelholz, University of British Columbia, *Global-scale external magnetic fields at Mars from Mars Global Surveyor data*

Global Environmental Change

Coordinator: Wenhong Liu

Melanie K. Behrens, Carl von Ossietzky University of Oldenburg, *Trace element inputs to the upper West Pacific from Nd isotopes and rare earth elements*

Rebecca Caldwell, Indiana University, *Developing a truly global delta database to assess delta morphology and morphodynamics*

Elizabeth H. Camp, Portland State University, *Mean kinetic energy budget of wakes within model wind farms: Comparison of an array of model wind turbines and porous discs*

Veronique Oldham, University of Delaware, *The complexation of Mn(III) in the sediments and water column of two coastal estuaries*

Hydrology

Coordinators: Newsha Ajami, Terri Hogue, Kolja Rotzoll, Laurel Saito, Tara Troy

Scott T. Allen, Louisiana State University, *Stable isotopes identified within-canopy processes during interception of rainfall*

Maartje Boon, Imperial College London, *3D observations of dispersion, mixing and reaction in heterogeneous rocks*

Andrea Cominola, Polytechnic University of Milan, *Modeling and managing urban water demand through smart meters: Benefits and challenges from current research and emerging trends*

David Dralle, University of California, Berkeley, *Using statistical mechanics and entropy principles to interpret variability in power law models of the streamflow recession*

Lauren Foster, Colorado School of Mines, *Energy budget changes impact arid mountain hydrology more than rain-snow transitions*

Abby G. Frazier, University of Hawai'i at Mānoa, *Rainfall trends through time: A running trend analysis of Hawaiian rainfall*

Danielle Grogan, University of New Hampshire, *The use and re-use of unsustainably mined groundwater: A global budget*

Francisco J. Guerrero, Oregon State University, *Reconstructing historical changes in watersheds from environmental records: An information theory approach*

Skuyler Herzog, Colorado School of Mines, *Engineered hyporheic zones as novel water quality best management practice: Flow and contaminant attenuation in constructed stream experiments*

Faye Jackson, University of Birmingham, *Understanding and predicting spatio-temporal variability of temperature in Scotland's rivers: Implications for riparian land management*

Tyler King, Utah State University, *High resolution channel geometry from repeat aerial imagery*

Bonnie McGill, Michigan State University, *Agricultural liming, irrigation, and carbon sequestration*

Lieke Melsen, Wageningen University, *Parameter transferability across spatial and temporal resolutions in hydrological modelling*

Kevin Roche, Northwestern University, *Turbulent hyporheic exchange in permeable sediments*

Zeinab Takhiri, University of Minnesota, *Microwave signatures of inundation area*

Yumeng Tao, University of California, Irvine, *Precipitation estimation from remotely sensed data using deep neural network*

Natalie Teale, Rutgers, The State University of New Jersey, *Synoptic-scale atmospheric conditions associated with flash flooding in watersheds of the Catskill Mountains, New York, USA*

Kathryn Wheeler, University of Delaware, *Leaf leachate chemistry: Regional variation across three watersheds in the northeastern United States*

Tiantian Xiang, Arizona State University, *Impact of land surface conditions on the predictability of hydrologic processes and mountain-valley circulations in the North American monsoon region*

Gang Zhao, Texas A&M University, *Sensitivity of reservoir storage and outflow to climate change in a water-limited river basin*

Mineral and Rock Physics

Coordinator: Heather Watson

Satoru Asayama, Osaka University, *Ultrafine particles preserved in the fault gouge of the Arima-Takatsuki Tectonic Line, Japan*

Tess Caswell, Brown University, *Creep and the characteristic length scale of strain-energy dissipation in polycrystalline ice: implications for tidal dissipation*

Bethany Chidester, University of Chicago, *Metal-silicate partitioning of lithophile elements at high pressures and temperatures*

Natural Hazards

Coordinators: Phu Nguyen, Daniel Write

Rui Chen, Northwestern University, *Determination of tsunami warning criteria for current velocity*

Qinghai Kong, University of California, Berkeley, *Smart-phone MEMS accelerometers and earthquake early warning*

Pablo Valenzuela, University of Oviedo, *BAPA Database: A landslide inventory in the Principality of Asturias (NW Spain) by using press archives and free cartographic servers*

Near Surface Geophysics

Coordinators: Xavier Comas, Fred Day-Lewis, Sarah Kruse, George Tsoulias

Nils Gueting, Forschungszentrum Jülich, *High resolution imaging of aquifer properties using full-waveform GPR tomography*

Seogi Kang, University of British Columbia, *Revisiting the time domain induced polarization technique, from linearization to inversion*

Megan Miller, Arizona State University, *Spatiotemporal distribution of strain field and hydraulic conductivity at the Phoenix valley basins, constrained using InSAR time series and time-dependent models*

Henry Schreiner, University of Texas at Austin, *Measurement over large solid angle of low energy cosmic ray muon flux*

Emily Voytek, Colorado School of Mines, *Identifying hydrologic flowpaths on arctic hillslopes using electrical resistivity and self potential*

Nonlinear Geophysics

Coordinator: Kunlun Bai

Noah Gabriel Randolph-Flagg, University of California, Berkeley, *Evenly-spaced columns in the Bishop Tuff as relicts of hydrothermal convection*

Ocean Sciences

Coordinator: Victoria Coles

Chawalit Charoenpong, Massachusetts Institute of Technology, *Stable isotope evidence for abiotic ammonium production in the hydrothermal vent fluids from the Mid-Cayman Rise*

Emily Newsom, University of Washington, *The strong control of sea ice dynamics on lower cell circulation changes*

Paleoceanography and Paleoclimatology

Coordinator: Matthew Kirby

Benjamin Hatchett, University of Nevada, Reno, *A medieval perspective of historical California and Nevada droughts*

Allison Jacobel, Columbia University, *130 kyr of dust fluxes in the equatorial Pacific: Implications for ITCZ movement and intensity*

Julia Kelson, University of Washington, *Reconciling empirical carbonate clumped isotope calibrations: A comparison of calcite precipitation and acid digestion methods*

Planetary Sciences

Coordinators: Nathan Bridges, Sarah Stewart

Madison Douglas, Massachusetts Institute of Technology, *Analysis of volcanic deposits on venus using radar polarimetry*

Peter Gao, California Institute of Technology, *Frozen fractals all around: Aggregate particles in the plumes of Enceladus*

Kynan Hughson, University of California, Los Angeles, *Preliminary geological map of the Ac-H-5 Fejokoo Quadrangle of Ceres: An integrated mapping study using Dawn spacecraft data*

Lauren Jozwiak, Brown University, *Intrusive magmatism and explosive volcanism on the Moon and Mercury: Insights from floor-fractured craters*

Public Affairs

Coordinators: Denise Hills, Linda Rowan

Maya K. Buchanan, Princeton University, *Allowances for evolving coastal flood risk under uncertain local sea-level rise*

Kimberley Corwin, Boise State University, *Preparing for volcanic hazards: An examination of lahar knowledge, risk perception, and preparedness around Mount Baker and Glacier Peak, WA*

Jill Shipman, University of Alaska Fairbanks, *Developing short films of geoscience research*

Seismology

Coordinator: Miaki Ishii

Karianne Bergen, Stanford University, *Unsupervised approaches for post-processing in computationally efficient waveform-similarity-based earthquake detection*

Daniel C. Bowman, University of North Carolina at Chapel Hill, *High altitude infrasound measurements using balloon-borne arrays*

Laurence Cowton, University of Cambridge, *Volumetric measurements of a thin CO₂-saturated layer through time at the Sleiþner Field, North Sea*

Andreas Mavrommatis, Stanford University, *Repeating earthquakes confirm and constrain long-term acceleration of aseismic slip preceding the M9 Tohoku-Oki earthquake*

Pamela Moyer, University of New Hampshire, *Constraining earthquake source parameters in rupture patches and rupture barriers on Gofar transform fault, East Pacific Rise from ocean bottom seismic data*

Marija Mustac, Australian National University, *Contending non-double-couple source components with hierarchical Bayesian moment tensor inversion*

Frederic Wagner, Uppsala University, *Migration based event detection and automatic P- and S-phase picking in Hengill, southwest Iceland*

Space Physics and Aeronomy

Coordinator: Elizabeth Mitchell

Prayitno Abadi, Nagoya University, *East-west asymmetric of scintillation occurrence in Indonesia using GPS and GLONASS observations*

Haoming Liang, University of California, Los Angeles, *Impact of heavy ions on reconnection rate and dipolarization fronts during magnetotail reconnection*

Andrew Marsh, University of California, Santa Cruz, *The NuSTAR sensitivity to quiet-Sun transient events*

Ryan M. McGranaghan, University of Colorado Boulder, *Reconstruction of three-dimensional auroral ionospheric conductivities via an assimilative technique*

Christian Nabert, Technical University of Braunschweig, *Efficient estimation of MHD parameters from magnetosheath observations*

Vu Nguyen, University of Colorado, *Addressing the question of large-scale nonlinear wave coupling in the space-atmosphere interaction region*

Anthony Saikin, University of New Hampshire, *The geomagnetic condition dependence of the spatial distributions of EMIC waves observed by the Van Allen Probes*

Pawel Swaczyna, Space Research Centre of the Polish Academy of Sciences, *Helium energetic neutral atoms—A new perspective for heliospheric and extraheliospheric observations with IMAP*

Patrick Tracy, University of Michigan, *Relative heating of heavy ions observed at 1 AU with ACE/SWICS*

Hong Zhao, University of Colorado Boulder, *The relative deep penetrations of energetic electrons and ions into the slot region and inner belt*

Study of Earth's Deep Interior

Coordinators: Allen McNamara, Laurent Montesi, Sabine Stanley

Lauren Harrison, University of British Columbia, *The Hawaiian mantle plume from toe to head along the Northwest Hawaiian Ridge*

Emmanuel Njini, Oklahoma State University, *Mid-lithospheric discontinuity beneath the Malawi Rift, deduced from gravity studies and its relation to the rifting process*

Tectonophysics

Coordinators: Michele Cooke, Juli Morgan

Troy Barber, University of Texas at Arlington, *Controls on the formation of pulverized off-fault rocks: Laboratory investigations using Arkansas Novaculite*

Thomas Ferrand, Ecole Normale Supérieure de Paris, *High-pressure dehydration experiments of antigorite-olivine samples to explain seismicity in the lower Benioff plane*

Dawei Gao, University of Victoria, *On the possibility of slip-to-trench rupture in Cascadia megathrust earthquakes*

Emily Hopper, Brown University, *New insights on the final stages of the Appalachian orogeny in the southeast U.S.A.*

Cassidy Jay, Purdue University, *Kinematics and dynamics of the Main Ethiopian Rift*

Junle Jiang, California Institute of Technology, *Connecting depths of seismicity, fault locking, and coseismic slip using long-term fault models*

Robert McDermott, Utah State University, *Integrating hematite (U-Th)/He dating, microtextural analysis, and thermomechanical modeling to date seismic slip*

Christopher Thom, University of Pennsylvania, *Nanoscale characterization of fault roughness by atomic force microscopy*

Sarah Weihmann, University of Aberdeen, *Predicting fluid flow in stressed fractures: A quantitative evaluation of methods*

Volcanology, Geochemistry, and Petrology

Coordinators: Michael Bizimis, Eric Brown, Sarah Brownlee, Brian Dreyer, Nicholas Dygert, Qi Fu, Sarah Lambart, Noah McClean, Sean Mulcahy, Tyrone Rooney

Chelsea Allison, Arizona State University, *The plumbing system of a highly explosive basaltic volcano: Sunset Crater, AZ*

Thomas Benson, Stanford University, *The oldest known caldera associated with the Yellowstone hotspot: New geologic mapping, geochemistry, and ⁴⁰Ar/³⁹Ar geochronology for the northern McDermitt volcanic field, northern Nevada and southeastern Oregon*

Sophie Briggs, University of California, Santa Barbara, *The P-T history of the Alpine Schist, New Zealand: Constraining tectonic processes during the late stages of Gondwana breakup*

Andrew Fowler, University of California, Davis, *Alteration of crystalline and glassy basaltic protolith by seawater as recorded by drill core and drill cutting samples*

Elisabeth Gallant, University of South Florida, *Lava flow hazard assessment for the Idaho National Laboratory: A probabilistic approach to modeling lava flow inundation with MOLASSES*

Janine Krippner, University of Pittsburgh, *The 2005 and 2010 dome collapse driven block and ash flows on Shivelush volcano; Kamchatka: Morphological analysis using satellite- and field-based data*

Emma Liu, University of Bristol, *What controls the sizes and shapes of volcanic ash? Integrating morphological, textural and geochemical ash properties to decipher eruptive processes*

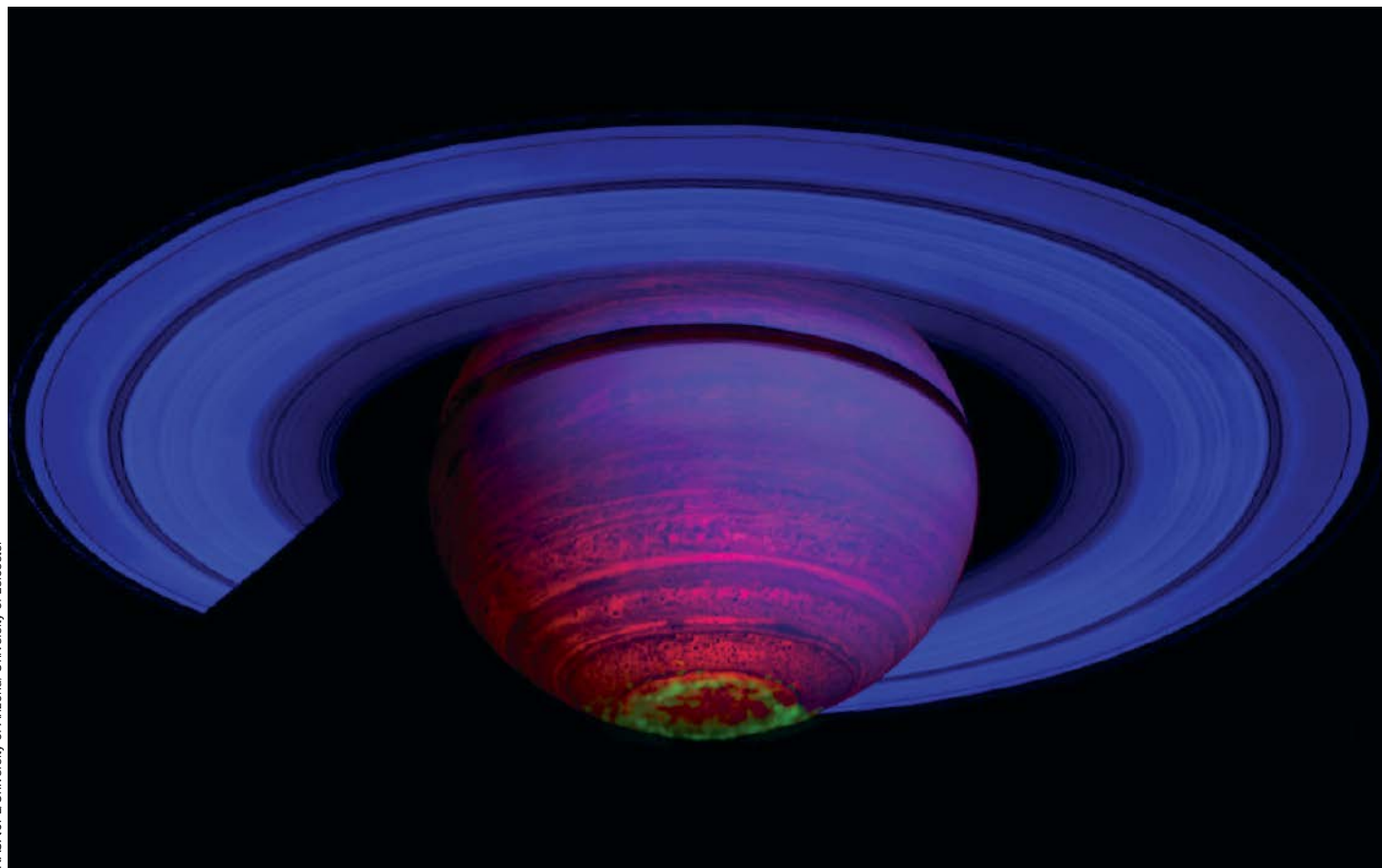
Jillian Schleicher, University of Washington, *Multiphase simulations constraining the characteristic volumes and efficiency of mixing within magmatic mushes*

Sara Worsham, University of Saskatchewan, *Using a novel Mg isotope tracer to investigate the dolomitization of the Red River Formation in the Williston Basin*

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Cassini Observes First Evidence of Saturn's Ionospheric Outflow



NASA/JPL/University of Arizona/University of Leicester

A false-color composite image, constructed from data obtained by NASA's Cassini spacecraft, showing the glow of the aurora about 1000 kilometers above the cloud tops of Saturn's south pole.

Magnetospheres are regions of space that are heavily influenced by the magnetic field of a nearby planet and can contain charged particles in the form of plasma from both external and internal sources. Earth's magnetosphere, for instance, is filled mostly with particles from the solar wind or, during periods of strong geomagnetic activity, its ionosphere—a region above 85 kilometers in which solar radiation strips molecules of their electrons to produce ions. In the case of Saturn, its moon Enceladus spews out water that is then ionized into H_2O^+ , O^+ , and OH^+ —the so-called water group ions—which are then transported throughout the magnetosphere.

At Earth, increased geomagnetic activity or compressions in the magnetosphere can increase the number of particles flowing out into the magnetosphere. This ionospheric outflow happens most easily at the poles, where the magnetic field lines open into a characteristic tail dragged out behind the planet by the solar wind.

Here Felici *et al.* report on an event measured by the Cassini spacecraft while it was traversing Saturn's magnetotail. At the time of the measurement, Saturn was undergoing a magnetospheric compression, and Cassini remotely observed aurora on Saturn's north pole. The composition of particles Cassini was measuring in the magnetotail

was also different from normal. The water group ions disappeared, but in their place, Cassini measured particles much more consistent with what would be expected for ionospheric outflow coming from Saturn's upper atmosphere.

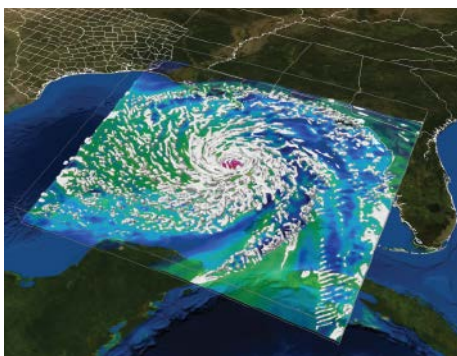
By measuring the flux of particles in the magnetotail and mapping them to the auroral outflow region, the researchers calculated that the total amount of mass emitted per second may be as large as the rate at which mass is spewed from Enceladus. It is unknown how much of this mass stays in the magnetosphere and how much escapes down the magnetotail and joins with the solar wind.

These are the first measurements that investigate what role ionospheric outflow plays at a giant planet and give a more dynamic picture of what Saturn's magnetosphere is like. Cassini is approaching its grand finale, where the new orbital configuration will allow an even clearer picture of what role the ionosphere may play as a mass source at Saturn. These studies will be complementary to the Juno mission, which is also interested in sources of magnetospheric composition. Juno is due to arrive at Jupiter in July 2016. (*Journal of Geophysical Research: Space Physics*, doi:10.1002/2015JA021648, 2016) —Rachael Jen-
sema, Freelance Writer

Wind Shear Measures Help Predict Tropical Cyclones

Spectacular tropical storms are a common threat for communities around the globe, but the physical mechanisms that drive storm conditions are under investigation. Here *Tao and Zhang* conduct experiments to better understand the relationship between storm development and vertical wind shear, the difference in wind speed and direction over different altitudes in the atmosphere. Wind shear can influence the shape and behavior of tropical storms, and parsing this connection has far-reaching benefits: Predicting vertical wind shear near a tropical cyclone contributes to more accurate forecasts of storm intensity—a valuable tool for both economic and humanitarian reasons.

The researchers used the Weather Research and Forecasting model to look at the impact of variations in vertical wind shear and moisture perturbation. They created a control thermodynamic environment, with a constant sea surface temperature of 27°C and an initial storm vortex with maximum surface wind speed of 15 meters per second at a radius of 135 kilometers. They used this foundation to explore changes in storm behavior under



Tao and Zhang's real-time forecast of Hurricane Ike (2008), showing the storm developing in the gulf and making landfall on the coast of Texas. Credit: Fuqing Zhang and Yonghui Weng, Pennsylvania State University; Frank Marks, NOAA; Gregory P. Johnson, Romy Schneider, John Cazes, Karl Schulz, Bill Barth, The University of Texas at Austin

different environmental shear or minute initial moisture perturbations.

The team found that in scenarios with a mean environmental shear of 6 meters per

second, random shear perturbations with relatively high variability had a bigger influence on storm development and intensification than random moist convection. Under most conditions, the random nature of convection had some influence on the onset of “rapid intensification” by affecting storm structure and changing the strength of storm circulation; a slower circulation is less resistant to environmental shear, and the storm can unravel.

Overall, the researchers found that although predictability of sheared storms can be intrinsically limited given even minute initial uncertainties, inaccurate wind shear predictions translated to big errors in tropical cyclone prediction. Identifying the role of these variables contributes to a better scientific understanding of the complex behavior of Earth’s atmosphere. Further research may help translate this knowledge into improved forecasting capabilities and better serve the communities affected by tropical cyclones. (*Journal of Advances in Modeling Earth Systems* (JAMES), doi:10.1002/2015MS000474, 2015)

—Lily Strelch, Freelance Writer

Building New Ways to Think About Arctic Freshwater

Much of the global climate is driven by forces that originate in the Arctic. The high-latitude regions of planet Earth shuffle and convert energy between phases and exchange heat between ocean and air. Many factors—like the thermohaline circulation, which reverses direction at the poles as warm salty water releases heat into the air and sinks down to the bottom—are heavily influenced by the ocean’s salinity, and thus, the movement of freshwater into and around the Arctic plays an important role in shaping both regional and global climate.

Here *Carmack et al.* compile a review of literature addressing the dynamic role of freshwater in the Arctic Ocean. The review is focused on three major factors: the inputs of freshwater into the system, such as rivers and precipitation; how and where freshwater is stored and transported in the Arctic Ocean; and the factors that remove freshwater from the area. Overall, the review affirms the widely held opinions that the Arctic Ocean is

freshening, warming, and losing sea ice. They further conclude that “there is little of climate and biogeochemical importance that happens in the Arctic that is not constrained by the flux and state of fresh water.”

In recent decades, much research on these topics has raised the questions of “tipping points” and “system flips,” where feedbacks in the system compound to rapidly cause massive reorganization of global climate over very short periods of time—a truncation or reorganization of the thermohaline circulation or of food web structures, for instance, caused by the loss of sea ice or warming ocean temperatures. The authors conclude that climate change in the Arctic Ocean is “probably not” extreme enough to cause a massive reorganization of global climate patterns. But because the stakes are so high, the researchers also urge for more studies to track the movement of freshwater throughout the region with greater resolution and detail so that models—both conceptual and



The melting of icebergs discharged from Greenland is contributing to the Arctic's freshwater budget.

computational—can be more tightly constructed to match the realities of our changing planet. (*Journal of Geophysical Research: Biogeosciences*, doi:10.1002/2015JG003140, 2015) —David Shultz, Freelance Writer

New Model Improves Predictions of Shallow Landslides

Because landslides damage infrastructure and can pose a threat to human life, scientists have long sought to predict when and where they might occur. Landslides happen where a disturbance such as heavy rainfall, snowmelt, or an earthquake disrupts the balance between soil strength and gravity. Shallow landslides, in particular, are most often triggered by the infiltration of intense rainfall. The resulting increase in water content reduces the soil's cohesion, which, in turn, helps destabilize the slope.

To better understand and predict the development of rainfall-induced landslides, *Anagnostopoulos et al.* recently created HYDROListhesis, a new process-based model designed to more realistically predict the interactions between subsurface hydrology and landslide initiation. The model incorporates key hydrologic and geotechnical conditions that have not generally been included in earlier models. A soil suction module, for instance, accounts for changes in soil cohesion during periods of wetting and drying. The new

model also integrates the role of preferential water flow paths, such as fissures, cracks, and root holes, in landslide formation, something rarely included in previous models despite experimental evidence showing that such paths can play an important role in shallow landslide initiation.

As a test of HYDROListhesis's predictive abilities, the team applied the model to central Switzerland's Napf catchment, an alpine region that experienced many shallow landslides following an intense rainfall event in 2002. The results demonstrate that shallow landslides occur in both saturated and unsaturated conditions and that the critical depth for landslide initiation is 0.2 to 1.2 meters—a finding consistent with field evidence. The simulations suggest that boundary conditions, such as soil depth, play an important role in model performance, as do the newly incorporated hydrologic and geotechnical components.

Although it still needs to be vetted on catchments of different sizes and varying cli-



Shallow landslides, like this one near the village of Randa in Switzerland, may be easier to predict thanks to a new model that incorporates key hydrologic and geotechnical conditions not included in most previous models.

mate regimes, HYDROListhesis has demonstrated the potential to help scientists better understand the complex dynamics controlling shallow landslide initiation. (*Water Resources Research*, doi:10.1002/2015WR016909, 2015)

—Terri Cook, Freelance Writer

Details of Gas Flow in Wetland Plant Roots Unearthed

Despite the old saying “dead as dirt,” Earth's soil is an incredibly rich and dynamic environment. Invertebrates, microbes, and plants all interact beneath the surface in a complex dance that determines the health of ecosystems and plays a part in larger biogeochemical cycles. Plants, in particular, play a major role in mediating mass transfers among different compartments of the biosphere. Their root systems create twisting underground superhighways of gases and liquids, moving the molecules essential for life up into the plant to be broken apart or added together as needed and generating waste products to be exhaled and excreted into the air. The gas transporting capacity of wetland plants is due to porous, gas-filled root tissues called aerenchyma that transport oxygen to the anoxic root zone and also facilitate gas transfer in the opposite direction, from soils to atmosphere.

Scientists have spent considerable time investigating how key gases, such as oxygen and methane, are exchanged between earth and atmosphere by plants. The generalized

kinetics of gas flow into root systems is still poorly understood, however. Here *Reid et al.* attempt to determine the speed at which wetland plants move various trace gas molecules through their root system.

The team relied on an experiment known as a “push-pull test,” in which a combination of dissolved gas and nonvolatile tracers are co-injected into a vegetated wetland soil (pushing) and their concentrations are measured over time by sampling (pulling) the gases at the site of injection. The key to this experimental setup is to inject one or more volatile tracers, which will readily partition into gas-filled root tissues and be transported by the aerenchyma network, and a nonvolatile bromide tracer, which will only dissipate in pore waters by diffusion. By comparing the ratio of the tracers at the site of injection over time, scientists can determine how readily the dissolved gases are being taken up into the root network compared to their nonvolatile counterpart.

The authors analyzed sulfur hexafluoride and helium gases. These two gases were chosen because they are chemically inert and,

because of their different properties, were expected to establish upper and lower limits on gas exchange rates. Measurements were taken at multiple depths and locations within a New Jersey tidal marsh to establish a rough estimate for how quickly gases can migrate from saturated soils into root systems in the wild. The density of the root system proved to be a particularly important variable, with more developed root systems significantly enhancing gas exchange.

Although sulfur hexafluoride and helium are not themselves relevant to ecological processes in wetlands, the rates inferred from those tracers should bookend the minimum and maximum rates exhibited by critical biogenic gases like carbon dioxide, methane, and nitrous oxide. This is an important step in understanding how physical-chemical transport systems interact with biological nutrient cycling in wetland soils, with implications for the greenhouse gas balances of wetland ecosystems. (*Water Resources Research*, doi:10.1002/2014WR016803, 2015)

—David Shultz, Freelance Writer

Radar Technique Shows Magma Flow in 2014 Cape Verde Eruption



Nicole Richter

The 2014–2015 eruption of Pico do Fogo destroyed the villages of Portela and Bangaeira. Now satellite radar-detected surface changes are helping scientists understand what happened.

On 23 November 2014, the Pico do Fogo volcano began to erupt, forcing nearby residents to evacuate. By early December, slow-moving lava flows had destroyed two villages, and the eruption continued until early February. Now *González et al.* have used a new satellite imaging system to model the subsurface path of the magma that fed the eruption.

Pico do Fogo is a 2829-meter composite volcano located on Fogo Island in Cape Verde, an archipelago about 480 kilometers off the west coast of Senegal. It has erupted at least 26 times in the past 500 years, including in 1995.

The most recent eruption was captured by the European Space Agency's Sentinel-1 satellite, launched in April 2014. The team used

the satellite's interferometric synthetic aperture radar (InSAR) system to map small movements of the ground over the course of the eruption. This marked the first time a significant ground deformation event was imaged with Sentinel-1's new InSAR technique—terrain observation by progressive scans (TOPS)—in which the radar beam is carefully steered to improve image quality.

The TOPS InSAR images revealed changes in the volcano's surface topography, allowing the researchers to model magma flow underneath. They found that the magma likely rose rapidly under the cone and then veered to the southwest flank of the volcano, where it erupted from an elongated crack, or fissure.

The TOPS technique provided the team with better surface coverage than that of the GPS system that is typically used to monitor Pico do Fogo. The researchers also compared the Sentinel-1 data with imagery of the same event captured by Canada's RADARSAT-2 satellite; the additional data supported their magma flow model.

Following their success with the Pico do Fogo eruption, the scientists believe that Sentinel-1's TOPS InSAR technique has the potential to be used to study other natural hazards, including earthquakes and landslides. (*Geophysical Research Letters*, doi:10.1002/2015GL066003, 2015) —Sarah Stanley, Freelance Writer

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Atmospheric Sciences

FACULTY POSITION - ATMOSPHERIC & SPACE PHYSICS

The Department of Physics and Astronomy at Clemson University invites applications for a tenure-track faculty position at the Assistant Professor or higher level to expand the atmospheric and space physics group. We seek candidates with a strong background in whole atmosphere general circulation modeling with emphasis on Earth's upper atmosphere and ionosphere. The atmospheric and space physics group within the department has currently strong research efforts in rocket and ground-based experiments, satellite diagnostics, and empirical modeling. Required qualifications include a PhD in Physics or closely related field and a record of substantive research. The successful candidate will be expected to establish vigorous externally funded research programs and to teach at both the undergraduate and graduate levels. Applications should be sent as a single PDF document to cuphysicsjob@clemson.edu and include a curriculum vitae, publication list, statements of research interests and accomplishments, and a research plan. Short-listed candidates will be asked to provide the names and addresses of three references, and a statement of teaching philosophy. Applicant evaluation will begin March 1 and continue until the position is filled. The starting date for the appointment is anticipated to be August 2016; however, a later starting date can be negotiated. Information about the department can be found at <http://physics.clemson.edu>. For further information, contact Professor Jens Oberheide at joberhe@clemson.edu or (864) 656-5163.

Clemson University is an Affirmative Action/Equal Opportunity employer and does not discriminate against any individual or group of individuals on the basis of age, color, disability, gender, national origin, race, religion, sexual orientation, veteran status or genetic information.

Research Associate in Atmospheric Sciences at Indiana University, Bloomington

Applications are invited for a Research Assistant in the Atmospheric Group of the Department of Geological Sciences, Indiana University. Research is aimed at understanding the dynamics of hurricanes and conducting numerical simulations of hurricane-like vortices. The successful candidate is expected to possess mathematical skill in compressible fluid and nonlinear dynamical systems. Knowledge and/or experience with numerical modeling is desirable. The candidate should be self-motivated, and be prepared to interact with atmospheric scientists and geophysicists. Candidates must have at least a bachelor degree in

applied mathematics, physics, atmospheric sciences, or related sciences. The candidate is expected to communicate results at scientific meetings and publish in peer-reviewed journals. Initial appointment for the position is one year, and can be extended to the second year upon successful performance. Salary is commensurate with experience. Interested candidates should review the application requirements and submit their application at: <https://indiana.peopleadmin.com/postings/2252>. Applications should include a statement of research, CV, and the names/contact information for three references. For more information, please contact Dr. Chanh Kieu (ckieu@indiana.edu), Department of Geological Sciences, 1001 E. Tenth Street, Bloomington, IN 47405, or Dr. Shouhong Wang (showang@indiana.edu).

Indiana University is an equal employment and affirmative action employer and a provider of ADA services. All qualified applicants will receive consideration for employment without regard to age, ethnicity, color, race, religion, sex, sexual orientation or identity, national origin, disability status or protected veteran status.

Geochemistry

STEVE FOSSETT POSTDOCTORAL FELLOWSHIP IN EARTH AND PLANETARY SCIENCE WASHINGTON UNIVERSITY IN SAINT LOUIS

The Department of Earth and Planetary Sciences at Washington University in Saint Louis invites applications for the Steve Fossett Postdoctoral Fellowship. The Department seeks outstanding candidates who will strengthen and complement existing areas of study, including both terrestrial and planetary geology, geochemistry, and geophysics. Candidates will be encouraged to collaborate directly with Faculty and students within the Department, and will be invited to lead a seminar in their area of expertise. Ideal candidates will have transdisciplinary interests, and will interact scientifically with a broad spectrum of the Department's members. This competitive postdoc is awarded for a one-year period, which may be extended to a second year. The annual salary is \$59,600 with additional research funds of \$5,000 per year. Applicants should contact a potential Faculty sponsor to discuss additional arrangements.

Please send resume, statement of research interests, and names and contact information for at least three references to:

Fossett Fellowship Committee
Department of Earth and Planetary Sciences

Washington University
Campus Box 1169
One Brookings Drive
St. Louis, MO 63130

or via e-mail: Fossett_Fellowship@levee.wustl.edu

Applications will be considered until the position is filled, but priority will be given to those received before April 15, 2016. Washington University is an equal opportunity/affirmative action employer.

Hydrology

Tenure-Track Assistant Professor Position GROUNDWATER HYDROLOGIST University of Wyoming

The Department of Civil and Architectural Engineering at the University of Wyoming invites applications for a tenure-track faculty position in Groundwater Hydrology at the Assistant Professor level. We seek a candidate with the interest and ability to develop and sustain a nationally competitive research program. The successful candidate must hold an earned doctoral degree in Civil Engineering or in a closely related discipline by the position start date. Registration as a professional engineer or professional hydrologist are desirable but not required. The successful candidate must be able to teach courses in fluid mechanics, hydraulics, hydrology, and water resources engineering. Also, the successful candidate must have the demonstrated ability to develop an externally funded research program in groundwater hydrology.

This position will become part of a major research thrust in water resources at the University of Wyoming. Groundwater resources are of immense importance to societal and ecological needs. Approximately half of Wyoming water resources are from groundwater, and subsurface resources provide critical water to agriculture, oil and gas development, and municipalities. There are tremendous research challenges in groundwater resulting from changing climate signals and human population patterns, and emerging techniques provide outstanding opportunities for groundwater hydrologists to better quantify the fate and transport of water in a changing west. We seek a groundwater hydrologist with experience in laboratory and field approaches for describing complex subsurface processes. Areas of specific interest include, but are not limited to, surface-groundwater interaction, unsaturated flow and contaminant transport.

As a member of the faculty of the Department of Civil and Architectural Engineering, the successful candidate will integrate his or her research with the goals of the new Wyoming Center for Environmental Hydrology and Geophysics (<http://www.uwyo.edu/epscor/wyechg/>) and provide academic support to the PhD program in Water

HIGP

Hawai'i Institute of Geophysics & Planetology

Assistant/Associate Researcher in Hydrogeophysics (Position Numbers 0088474/0088665). The Hawaii Institute Geophysics and Planetology (HIGP) and the Water Resources Research Center (WRRC), University of Hawaii at Mānoa, jointly seek a tenure-track Assistant/Associate Researcher (locus of tenure in HIGP) in hydrogeophysics specializing in geophysical techniques, including electromagnetic and magneto-telluric methods that are applicable to the study of aquifers, subsurface flow dynamics, and geothermal resources. The selectee will report to the HIGP and WRRC Directors. The level of State support will be equivalent to at least 9 months per year, with the remainder to be raised through external funds. The incumbent is expected to work in water research in collaboration with colleagues in HIGP, WRRC, and other Colleges at UH Mānoa (such as Engineering and Social Sciences), and is expected to seek and obtain extramural funding in support of these areas of research, to take an active role in student advising and teaching, and to publish research results in the refereed literature.

Full information on the position description, including minimum and desirable qualifications, can be found at: <http://workatuh.hawaii.edu> (search on position numbers). All applications must be made electronically to higp-search@higp.hawaii.edu, and limited to 25 Mbyte. Submit a letter of interest to the Chair HIGP/WRRC Search Committee, and include a curriculum vitae, official transcripts (copies acceptable with application, original required upon hire) and the names and contact information (phone and e-mail address) of at least three professional references. Initial review of applications shall begin on April 4th, 2016, and shall continue until the position is filled. The position is available July 1, 2016 or as mutually acceptable. For further information on UHM, visit: <http://www.manoa.hawaii.edu/>

The University of Hawaii is an equal opportunity/affirmative action institution and is committed to a policy of nondiscrimination on the basis of race, sex, gender identity and expression, age, religion, color, national origin, ancestry, citizenship, disability, genetic information, marital status, breastfeeding, income assignment for child support, arrest and court record (except as permissible under State law), sexual orientation, domestic or sexual violence victim status, national guard absence, or status as a covered veteran.



Resources, Environmental Science and Engineering (<http://www.uwyo.edu/wresep/>).

UW faculty have access to world-class computational resources as described at: <https://arcc.uwyo.edu/>. The department is supported by 22 tenured or tenure-track faculty and offers ABET-accredited baccalaureate programs in both civil engineering and architectural engineering to approximately 300 undergraduate students. The department also offers graduate programs at the Masters and PhD levels to roughly 60 graduate students.

Laramie is a picturesque and friendly town offering a reasonable cost of living, good K-12 public schools and easy access to outdoor activities in the Rocky Mountain region. Additional information on the Department, College, and Laramie is available at: <http://www.uwyo.edu/civil>, <http://ceas.uwyo.edu> and <http://www.laramie.org>.

Applications must include: 1) a letter of application, 2) a curriculum vitae including a list of publications, 3) a statement of research interests, 4) a statement of teaching interests, and 5) contact information for at least three references. Do not include supplemental information such as offprints of papers, reference letters, or transcripts. Review of applications will begin 15 September 2015 and continue until the position is filled. The preferred start date for the position is January 2016. Submit applications in a single PDF file to: water_search@uwyo.edu.

The University of Wyoming is an Equal Employment Opportunity/Affirmative Action employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin,

disability or protected veteran status or any other characteristic protected by law and University policy. Please see: <http://www.uwyo.edu/diversity/fairness>. We conduct background investigations for all final candidates being considered for employment. Offers of employment are contingent upon the completion of the background check.

Solid Earth Geophysics

ASSISTANT RESEARCH SCIENTIST - IODP Expedition Project Manager/Staff Scientist

The International Ocean Discovery Program (IODP) at Texas A&M University invites applications for an Assistant Research Scientist (Expedition Project Manager/Staff Scientist) in our Science Operations section. Preference will be given to applicants with expertise in petrology, inorganic (fluid) geochemistry, downhole logging, petrophysics, and sedimentology. However, applicants in any field of geoscience pertinent to IODP will be considered.

A Ph.D. in geosciences or related field, and demonstrated on-going research experience is required. Applicants must have a demonstrated fluency in written and spoken English. Experience as a seagoing scientist, especially in scientific ocean drilling, is preferred.

This position will serve as the Expedition Project Manager to coordinate all aspects of pre-cruise expedition planning, sea-going implementation, and post-cruise activities. These duties include sailing as the IODP scientific representative on a two-month IODP expedition approximately once every 1 to 2 years.

Individual scientific research, as well as collaboration with colleagues at

Texas A&M University in fulfilling its educational mission, is required.

This position will also provide scientific advice on laboratory developments in their area of specialization including scientific implementation of downhole logging on the JOIDES Resolution. Applicants must be able to cooperate and work harmoniously with others, have the ability to be an effective team leader, and foster collaboration among diverse scientific participants. Passing a new employee medical exam and annual seagoing medical exams are a requirement of the position.

Salary will be commensurate with qualifications and experience of the applicant. This is a regular full time position, contingent upon continuing availability of funds for IODP. We will begin reviewing applications on 16 May 2016, but will continue to accept applications until candidates are selected for interviews. Applicants may access the TAMU application at <https://jobpath.tamu.edu> and apply online with reference to Posting Number 000086FY16, attach a curriculum vita, list of published papers, statement of research interests, and names and addresses of three references. Quick Link -

<http://jobpath.tamu.edu/postings/93404>

Interdisciplinary/Other

CHEMICAL OCEANOGRAPHY - TENURE TRACK POSITION.

The Department of Chemistry and Biochemistry, at California Polytechnic State University, San Luis Obispo invites applications for a full-time, academic year, tenure track position beginning September 15, 2016. Area of research specialization is in Chemical Oceanography. Appointments are anticipated at the Assistant Professor rank. For details, qualifications, and application instructions (online faculty application required), please visit WWW.CALPOLYJOBS.ORG and search/apply to requisition #103924 Open until filled. Application review begins April 4, 2016. For further information about the Department of Chemistry and Biochemistry see <http://www.calpoly.edu/~chem>. EEO

VOLCANO COMPUTER SCIENTIST JOB

Overview: Are you a computer-scientist who has a passion for building high-quality software with real-world humanitarian applications? Do you want to use your computer-science skills to save lives and improve the understanding of volcanic processes?

Position: The US Geological Survey, Volcano Disaster Assistance Program (VDAP), a 30-year partnership of the U.S. Geological Survey and USAID's Office of Foreign Disaster Assistance announces the posting of a new professional job opportunity to lead the development of new software and computer-science applications for international volcano monitoring and hazard analysis. This is a permanent

federal position that is based at the Cascades Volcano Observatory in Vancouver, WA, USA. The position is will be filled at either the GS-12 (\$74,950/yr to \$97,434/yr) or GS-13 (\$89,125/yr to \$115,867/yr) level depending on qualifications. The position includes federal provisions for tenure- and merit-based promotions, health and life insurance and annual and sick leave among other benefits (see <http://www.usgs.gov/humancapital/pb/index.html>).

Responsibilities: Design, develop, document and maintain custom open-source software to monitor and analyze multi-parametric monitoring data from active volcanoes world-wide. Serve as the lead computer scientist for a small team of 20 professional scientists and technicians who respond to volcano crises world-wide and assist international partners in forecasting eruptions and assessing volcanic hazards. Write new code and review existing source code to identify and solve problems and to improve human-machine interfaces. Train international partners in use of computer systems.

Requirements: Bachelor's degree in Computer Science or a Bachelor's Degree with 30 semester hours in mathematics, statistics and computer science with at least 15 of the 30 semester hours in any combination of mathematics and statistics and including differential and integral calculus.

1. Expertise in software coding and data processing on multiple operating systems using the programming languages Java and C. Python or other object-oriented languages are also desired. 2. Knowledge of computer science and system design as needed to develop and document new computer systems (e.g., software for data acquisition, analysis and storage with effective human computer interfaces (HCI). 3. Knowledge of relational database programming and theory. 4. Ability to design computer interface and communication systems (e.g., TCP/IP, multi-OS communications, data bus communication and serial (USB, RS232) protocols). 5. Knowledge of physical sciences or mathematics. 6. Ability to communicate effectively with project personnel and international counterparts in order to document and transfer knowledge of computer systems.

The organization: More information about the U.S. Geological Survey and the VDAP program is available at: <http://volcanoes.usgs.gov/vdap/>. More information about this position and job applications will be available starting on 03/28/2016 by searching for the position numbered SAC-2016-0136 at the following website: <https://www.usajobs.gov/>. Applications must be received digitally through this website before midnight EST on 04/11/2016 and must include scanned copies of undergraduate (and graduate if applicable) transcripts. USGS is an equal opportunity employer; however, the position is open to U.S. Citizens only.

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Postcards from the Field

Greetings,

Here in central Australia, the summer wet season can be quite spectacular. In this photograph, you see the build up during the 2014–2015 summer wet season. As the clouds portend, this was to be a magnificent storm (receiving 38 millimeters of rainfall on the day of this photograph and 55 millimeters 5 days later).

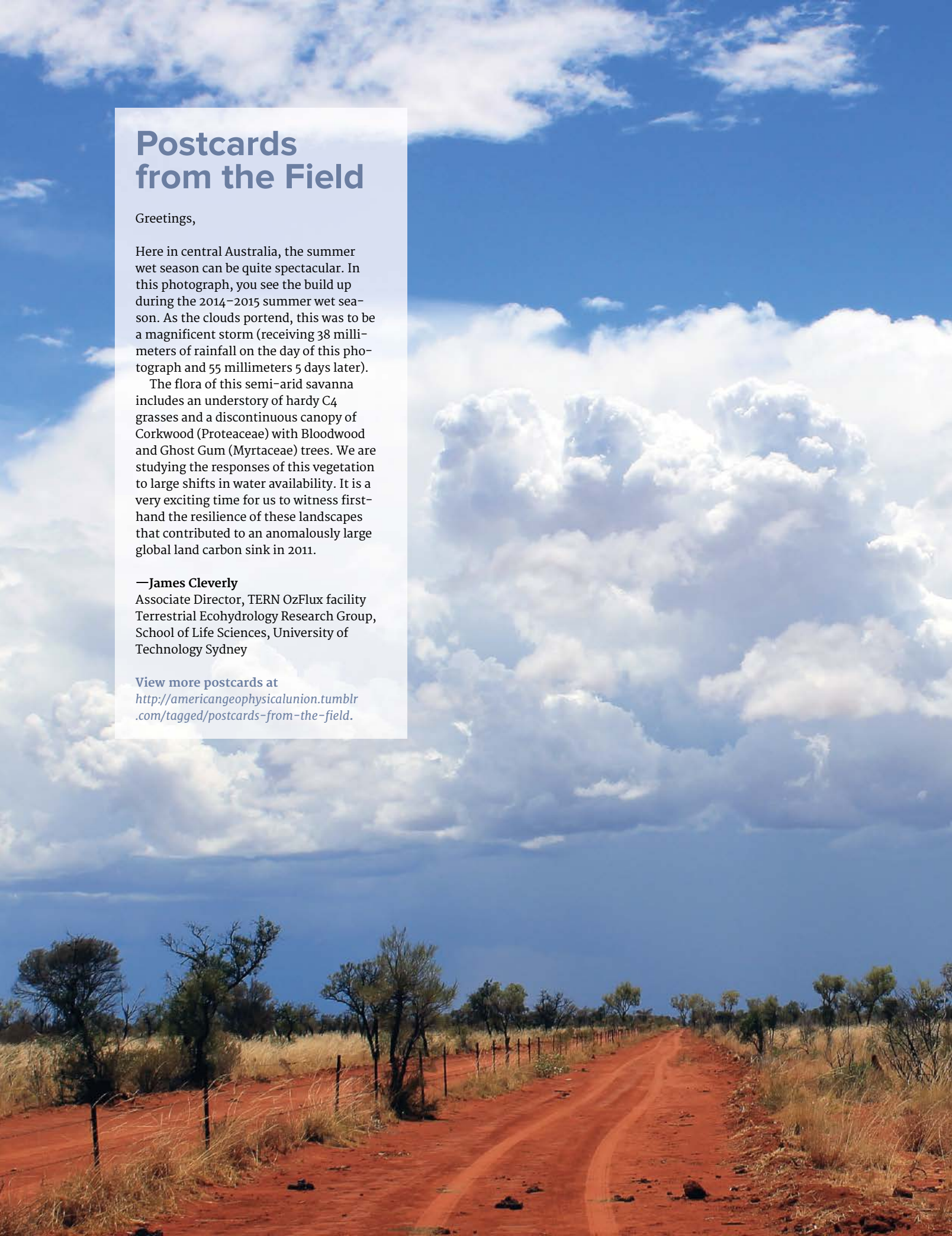
The flora of this semi-arid savanna includes an understory of hardy C₄ grasses and a discontinuous canopy of Corkwood (Proteaceae) with Bloodwood and Ghost Gum (Myrtaceae) trees. We are studying the responses of this vegetation to large shifts in water availability. It is a very exciting time for us to witness firsthand the resilience of these landscapes that contributed to an anomalously large global land carbon sink in 2011.

—James Cleverly

Associate Director, TERN OzFlux facility
Terrestrial Ecohydrology Research Group,
School of Life Sciences, University of
Technology Sydney

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